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DATA ACQUISITION AND ANALYSIS FOR CAMOUFLAGE DESIGN

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The report describes efforts to measure the spectral characteristics of various vegetative terrains under sunlighted and overcast conditions, both verdant and dormant, using a photographic approach. Exposures taken through narrow bandpass filters were scanned for densitometric data which were reduced to tristimulus values for individual picture elements. Neighboring pixels of similar chromaticity characteristics were clustered to produce a facsimile of the original scene in 3, 4, or 5 average representative colors in CIELAB notation with spectral reflectance factors available.

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Summary

Decilog, Inc. has completed the first phase of an effort to develop a method for the spectral and textural characterization of terrains. This report details the photographic and computer techniques employed in the acquisition of spectral data for several typical temperate zone scenes at two distances for verdant and dormant conditions under both clear and cloudy skies. Scene representation by color-averaged areas, called domains, results from the software and can be viewed on both CRT display and pen and ink plot. The number of domains allowed in a scene, variable from three to five, was kept small to allow simple reproduction for design of camouflage patterns for clothing and shelters.

The terrain scenes were photographed on panchromatic film using seventeen narrow bandpass filters covering the visible spectral region from 400 nanometers to 700 nanometers, centered every twenty nanometers. A set of spectrally characterized gray tiles was included in each exposure to enable normalization of densitometric data for the reconstructed scene. Using the appropriate illuminant data and the 1931 standard observer, this discrete spectral data for each picture element was converted to tristimulus values. Neighboring pixels of similar colors are clustered into domains, the chromaticity of which is the result of the Euclidean clustering or averaging carried out in 1976 CIELAB color space. The size and shape of these domains, along with color, provide an approximation of the way in which terrains are perceived by the eye. Agreement between this procedure and independent measurements is shown to be good.

Successful completion of this effort will provide an objective method of designing camouflage measures, thereby freeing the developer from reliance upon subjective approaches.

PREFACE

The reported work was performed for US Army Natick R&D Laboratories under Contract No. DAAK60-79-C-0072 with Mr. Alvin O. Ramsley, Project Officer. The Decilog effort was ably led by J. Richard Goldgraben. This work is part of Project 1L162723AH98, Clothing, Equipment, and Shelter Technology; Task AB, Passive Countersurveillance Measures for the Individual Soldier.

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DATA ACQUISITION AND ANALYSIS FOR CAMOUFLAGE DESIGN

1. INTRODUCTION

This report presents the results of a research program to acquire data on the spectral and spatial characteristics of natural vegetative terrains and to develop methodologies for the analysis of these data as an aide in the design of camouflage patterns for field clothing and large cloth shelters. The program has been concerned with camouflage for the visible spectrum and for human observers. The applicability of the methodology can, however, be extended to the near infrared and to photographic and electro-optic detection systems.

The fundamental problem in the design of camouflage for clothing and shelters is to determine the combination of colors and shapes which have the greatest effect on reducing the probabilities that the camouflaged object will be detected, recognized, and identified. Because the processes involved in the visual detection of objects against textured backgrounds are extremely complex (involving both psychophysical and "higher order" cognitive functions), the solution to the above problem is not a simple one. Experience has shown,[1] however, that effective, although not necessarily optimum, countersurveillance with camouflage can be achieved using psychophysical correlations alone. It has been demonstrated that probabilities of detection are reduced when the spatial and spectral str''cture of an object correlate well with the corresponding structure in the background. The approach utilized in this research program is based on psychophysical principles only.

Data from vegetative terrain backgrounds are acquired by photographic and digitization procedures. Computer programs generate spectral reflectance curves for each resolution element in the scene and analyze the colorimetric

[1]D. C. Cottington, C. H. Ulrich, and R. M. Wroblewski, MASSTER Camouflage Evaluation Program, Phase II; Verdant Camouflage Uniform Pattern Evaluation, MASSTER Test Report No. FM 204B, Modern Army Selected Systems Test, Evaluation and Review, Fort Hood, TX 76544, 21 Nov 75 (AD B008 620).

characteristics of the terrain in terms of 1976 CIE (L*a*b*) color coordinates. Among the outputs of the computer programs is a graphic map showing the shape and distribution of regions in the scene possessing similar colorimetric characteristics. The spectral and spatial properties of these regions are to be used as the basis for the design of 3-, 4-, or 5-color camouflage patterns.

Terrain data were acquired for vegetative terrains typical of the temperate regions of Europe and North America in both the dormant and verdant state. Data for both front-lighted direct solar illumination and solar illumination with moderately overcast sky conditions were obtained.

This report summarizes the technical aspects in the development of the data acquisition and analysis procedure and presents recommendations for further possible software development. Full documentation of the Data Processing and Analysis Software and of the Photographic Data Acquisition and Digitization Procedures are contained in separate volumes entitled:

Procedures for the Acquisition and Analysis of Terrain Data for Camouflage Design

VOLUME I Software Manual[2]

VOLUME II Manual for Photographic Data Acquisition and Film Digitization[3]

The data processing and analysis software has been implemented on the UNIVAC 1106 computer located at the Natick Research and Development Laboratories.

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[2] J. R. Goldgraben and B. Engelberg, Procedures for the Acquisition and Analysis of Terrain Data for Camouflage Design, Volume 1, Software Manual, Decilog, Inc., Melville, NY, March 1981.

[3] J. R. Goldgraben and B. Engelberg, Procedures for the Acquisition and Analysis of Terrain Data for Camouflage Design, Volume 2, Manual for Photographic Data Acquisition and Film Digitization, Decilog, Inc., Melville, NY, March 1981.

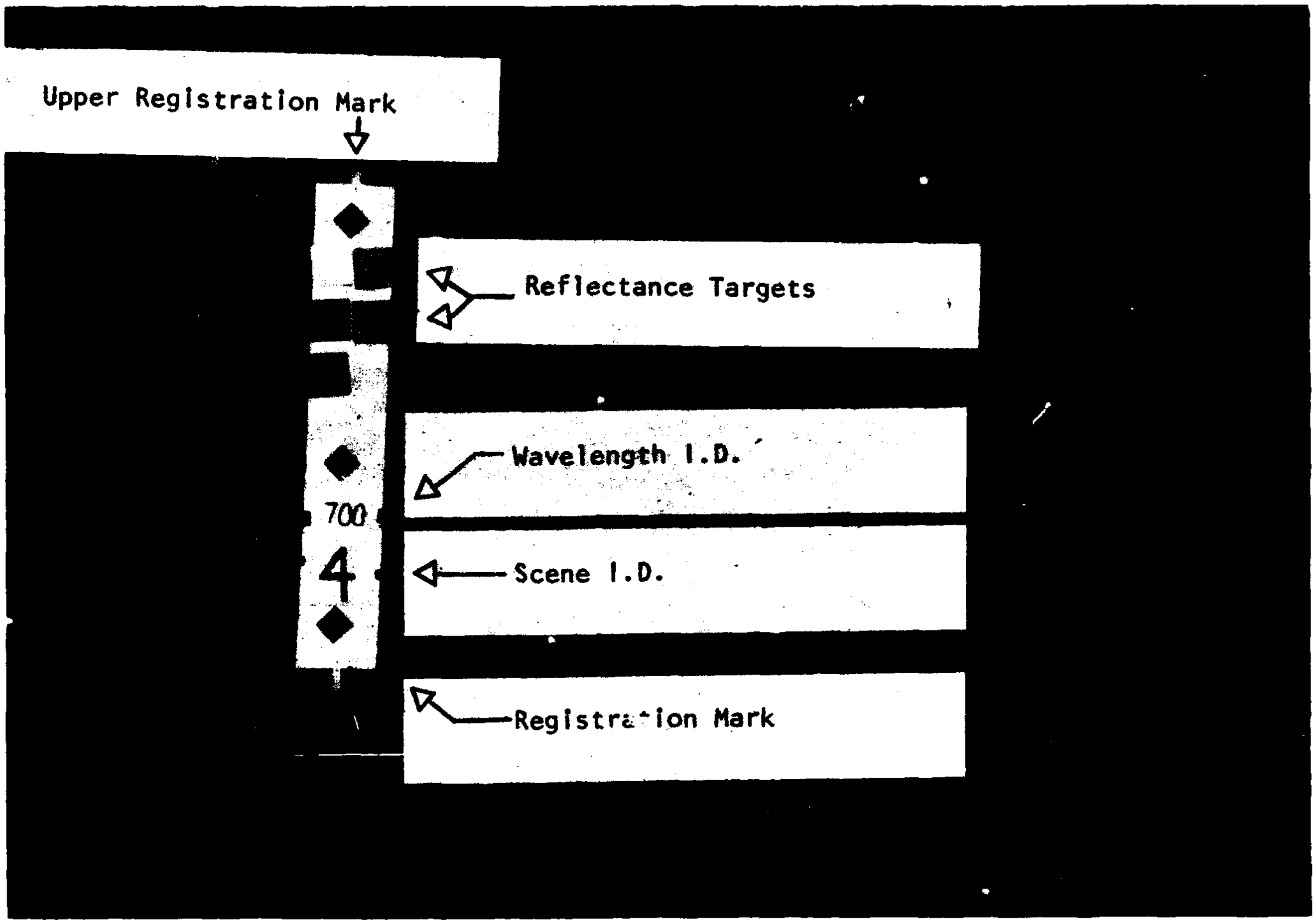


FIGURE 1. Target Board Used in Photographic Data Acquisition

FIGURE 2. Photographic Equipment

2. TECHNICAL APPROACH

a. Overview

The terrain analysis methodology is comprised of two main functions:

(1) Development of a terrain reflectance data base.

(2) Analysis of the terrain data.

Terrain data are acquired by taking photographs of each scene with narrow pass band 3 cavity dichroic interference filters and a 28-mm f/4 lens on black and white 35-mm transparency film (Kodak Linagraph Shellburst No. 2476). Each photograph represents the radiance distribution in the scene at the wavelength corresponding to the center of the filter pass band. Filter bandwidths at the half transmission points are typically 9 to 11 nanometers.

A special target board containing five calibrated 6" x 6" diffuse reflectance standards and registration marks is placed alongside the scene and included in each photograph (See Figure 1). The reflectance standards provide a calibration between film density and scene reflectance at each wavelength interval. The registration marks permit registration among the exposures for each scene.

The exposure setting for the camera is calculated from a measurement of the average radiance in the scene area. This radiance is measured with a radiometer fitted with a 4^{o} field of view limiter and the same narrow band filter used to expose the film. Figure 2 shows the camera and radiometer.

Spectral data are acquired and processed at two levels of resolution and scene area. The high resolution data, which is appropriate for camouflage of field clothing viewed at short distances, resolves down to 1.45 cm and encompasses a scene area of approximately 2 m x 2 m or 140 x 140 scene pixels. This resolution is equivalent to one minute of arc at 50 meters. The low resolution data, which is appropriate for large shelters and large viewing distances, resolves to 14.5 cm, the equivalent of one minute of arc at 500 meters, and encompasses a scene area of approximately 10 m x 30 m or (70 x

120 pixels). The high resolution and low resolution data are called the NEAR and FAR data, respectively.

The interference filters which are mounted on the camera produce vignetting of the image at aperture settings of f/2.8 and f/4. The extent of this vignetting in the film plane was determined by photographing a uniformly illuminated target and scanning the resulting image with a microdensitometer. The film digitization is uniform within circular areas of diameter 7 mm and 11 mm, respectively, for the f/2.8 and f/4 settings on a 28-mm lens. The distance at which photographs are taken have been selected so that the scene area (including the reflectance target boards) are within an 11-mm central uniform field area. For the near-range photographs with 2-m x 2-m scene area, the distance from camera to scene is 23.5 feet. For the long range photographs with 10-m x 30-m scene area, the correpsonding distance is 265 feet. All exposures were taken with the f/stop set at f/4 or smaller. At these distances, 1.45 cm resolution elements in the near range scenes will image at spatial frequencies of 18 cyc/mm on the film. The 14.5 cm resolution elements on the long-range photographs will image at 20 cyc/mm. At these frequencies, the Shellburst film has MTF values of 90% and 85%, respectively.

The target board containing the registration marks and the reflectance standards is placed directly in front of the scene for the near-range photographs. For the long-range photographs, the target is placed 100 feet from the camera. With this placement, the images of the reflectance standards on the film will subtend at least two resolution elements and will not be subjected to any MTF degradation.

Transparencies of each scene exposure are digitized with a scanning microdensitometer. The microdensitometer measures the optical density of the film at each point in a specified array pattern and records the data on magnetic tape. The film density of each reflectance standard and the location of the target registration marks in the digitizer coordinate reference frame are entered manually by the operator as part of the file identification header. These data are also stored on the magnetic tape.

Computer programs then read the files on the magnetic tape output of the film digitizer and generate basic data files containing reflectance values at each of the photographed wavelength intervals for each scene pixel.

The color/luminance characteristic of each spatial element (pixel) in a scene may be characterized by a single point in a three-dimensional color coordinate system once the spectral nature of the scene illumination is specified and the spectral reflectance curve of the element is known. In any real scene, the color coordinates associated with the multitude of scene pixels will be at many different locations in the color coordinate system. A fundamental task of the data analysis function is to take this multitude of color coordinate points and to cluster them into 3, 4, or 5 groupings. Each pixel is then assigned to one of the color coordinate groups. In effect, this process transforms the highly varied color/luminance scene into 3, 4, or 5 discrete and uniform color/luminance domains.

The clustering process requires the color coordinate system to have linear properties: the perceived color/luminance difference between two pixels is directly proportional to the Euclidean (vector) distance between the points in the color coordinate space. A system with this property is called a uniform color coordinate system.

The CIE Colorimetry Committee has recommended two uniform color coordinate systems in Supplement No. 2 to CIE Publication No. 15 (E1.3.1) 1971/(TC=1.3) 1978. These are the CIE 1976 (L*u*v*) space and the CIE 1976 (L*a*b*) space. Coordinates in both systems are functions of the x, y, and z chromaticity coordinates. These, in turn, are derived from the standard X, Y, and Z tristimulus values (for the 1931, 2° subtense observations), a specified or known scene irradiance, and the spectral reflectance characteristics in the scene. The CIE 1976 (L*a*b*) space, as defined in CIE Supplement No. 2, was used in this program since many textile and dyestuff industrial groups prefer to use this system for the definition of colorant mixtures. However, any of the published uniform chromaticity scales (UCS) could have been used in the analysis program.

Appendix A describes the Theory of the Photographic Data Acquisition Process.

Additional details of the 1976 CIE (L*a*b*) color coordinate system and the clustering processes are presented in Appendix B.

b. Technical Considerations in the Design of the Data Acquisition Process

Terrain data is acquired by photographic imagery and subsequent digitization by a microdensitometer. The photographic data acquisition process was selected because it met all technical requirements, was low in cost, readily implemented, and highly reliable in remote field locations.

Note that valid reflectance data cannot be obtained from photographic imagery using color film, since the relationship between the scene chrominance and the chrominance in the film are unknown. Chromaticity coordinates obtained from measurements on color film may or may not match those obtained from the actual scene. In general, color films produce colors which are more highly saturated than "real world" colors.

The technical considerations having the strongest impact on the design of the photographic data acquisition process are:

1) spatial resolution requirements
2) spectral resolution requirements
3) filter bandwidth
4) filter distortion
5) acquisition time
6) film sensitivity
7) dynamic range
8) non-linearities in the photographic process

Each of the above considerations is discussed below.

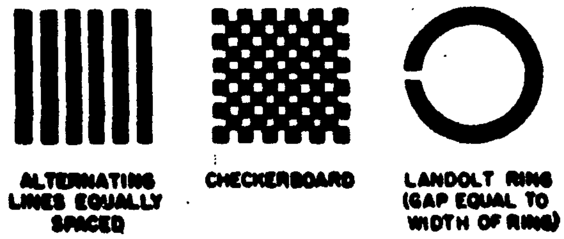


FIGURE 3. Common types of test targets for minimum separable acuity.*

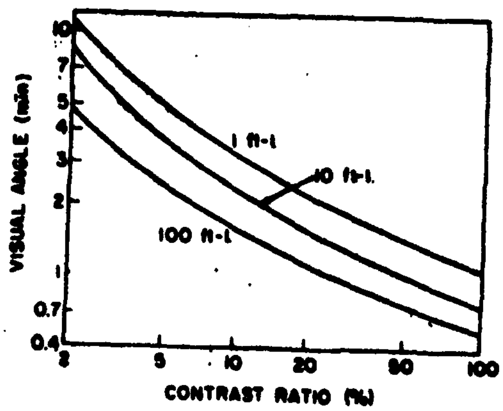


FIGURE 4. Minimum separable acuity as a function of background luminance (Cobb & Moss, 1928).

*Excerpted with permission from Human Engineering Guide to Equipment Design, American Institutes for Research, Washington, DC, 1972.

(1) Spatial Resolution

The level of spatial resolution required in the terrain data base is best defined by the psychophysical quantity "minimum separable acuity" or "gap resolution." This represents the smallest gap or space that the eye can see between parts of an object. Figure 3 shows three targets which are commonly used to measure gap resolution. Figure 4 shows the level of gap resolution for various background luminances and target contrasts.[4] These curves were obtained under laboratory conditions with subjects fixating on the patterns. The data implies that for outdoor field illumination, the gap resolution is about one minute of arc for a high contrast target. In a military situation, the target contrasts will be low and the observer will be searching an area rather than fixating on a specific point, both resulting in greatly reduced acuity. Since the resolution of the measurements should be finer than that of the eye, one minute of arc is an adequate level of resolution for data acquisition.

The acquisition and digitization of the terrain data must be compatable with the one minute of arc gap resolution. This requirement will be met if the digitized scene is composed of a matrix of resolution elements whose dimensions subtend one minute of arc at the minimum viewing distance. For example, for a 50-m viewing distance, the scene must be digitized into resolution elements which represent areas in the scene of 1.45 cm x 1.45 cm. At 500 m, the resolution elements will represent areas of 14.5 cm x 14.5 cm in the scene.

[4] Human Engineering Guide to Equipment Design, American Institutes for Research, Washington, DC, 1972.

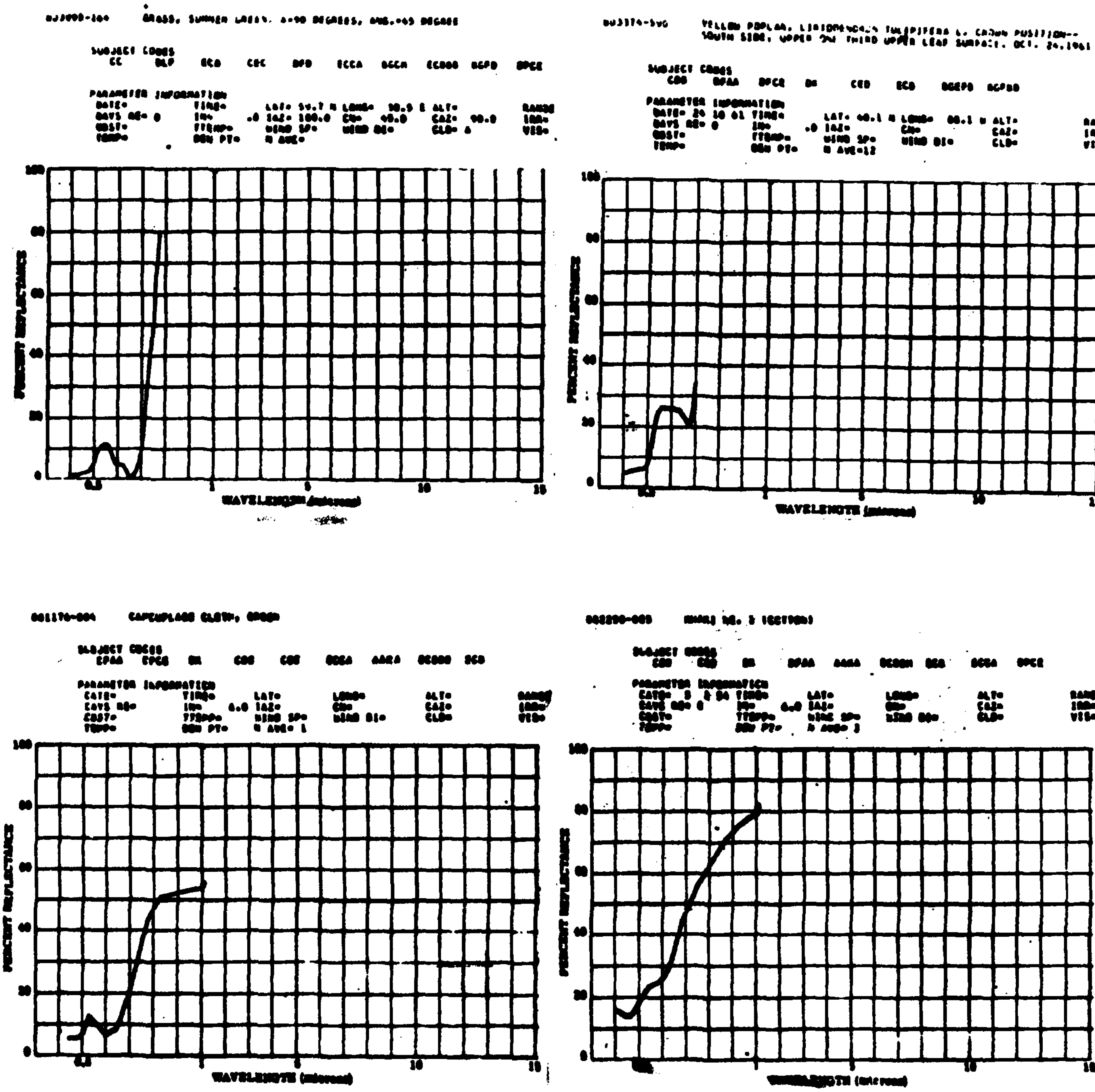
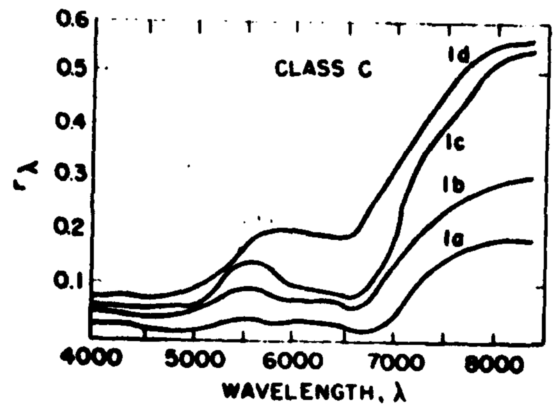


FIGURE 5. Selected Spectral Reflectance Curves*

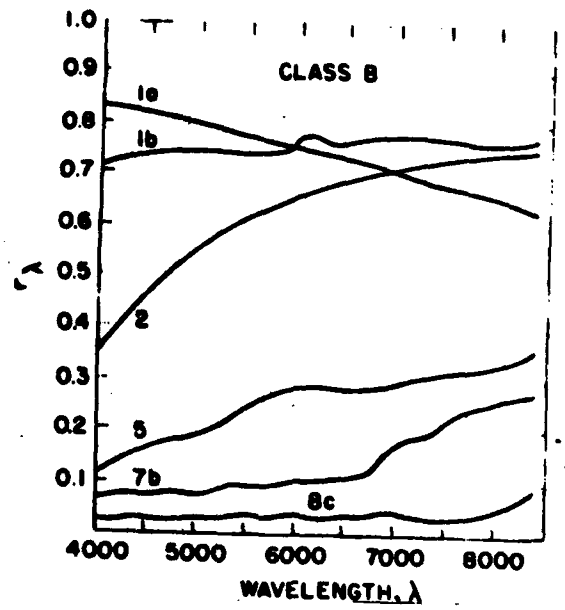
*Excerpted with permission from <u>Data Compilation of Target and Background Characteristics</u>, The University of Michigan, Air Force Avionics Laboratory, Wright Patterson Air Force Base, Ohio, July 1967.

FIGURE 6a.



Class C	Vegetative Formations
1a	Coniferous forests, winter
1b	Coniferous forests, summer
1c	Deciduous forest, summer
1d	Deciduous forests, fall

FIGURE 6b.



	Class B	Bare Areas and Soils
2	1a	Snow, fresh fallen
3	1b	Snow, covered with ice
4	2	Limestone, clay
8 {	5	Mountain tops, bare
	6a	Sand, dry }
6 {	7b	Clay, soil, wet
	8a	Ground, bare, rich soil, dry }
7	8c	Ground, black earth, sand, loam

FIGURES 6a and 6b. Spectral Reflectance of Terrain Features*

*Excerpted with permission from Handbook of Geophysics, Revised Edition. The Macmillan Company, New York, 1961.

(2) Spectral Resolution

Spectral data in each scene is obtained from a series of photographs taken through narrow band pass filters. In effect, the continuous spectral characteristics of the scene are being sampled at a discrete number of narrow spectral wavelength bands. It is necessary, therefore, to insure that the spacing between wavelength samples is close enough to detect the fine spectral characteristics of the scene elements.

Examination of the spectral reflectance curves of the typical normally occurring terrain features and camouflage cloth shows that all the significant variations in reflectance can be detected adequately if sampling is performed at 20-nm intervals. Figures 5 and 6 show some typical spectral reflectance curves.[5,6] A maximum of 17 spectral exposures, starting at 380 nm and proceeding in 20-nm increments up to, and including, 700 nm are, therefore, required.

Since the filters have a finite bandpass (typically 9 to 11 nm) the acquired data represents the average reflectivity over the filter bandpass.

(3) Filter Bandwidth

The transmission band of the optical filter should be less than the wavelength sampling interval. A filter whose transmission falls to 1% of the maximum at half the wavelength sampling interval will not distort the spectral data.

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[5] Data Compilation of Target and Background Characteristics, The University of Michigan, Air Force Avionics Laboratory, Wright Patterson Air Force Base, Ohio, July 1967.

[6] Handbook of Geophysics, Revised Edition, The Macmillan Company, New York, 1961.

TABLE 1 Shadow Movements Due to Earth's Rotation

Element Spacing Meters	Shift Time for Two Resolution Elements (min) S_o = 1.45-cm	S_o = 14.5-cm
0.05	66	664
0.10	33	332
0.50	6.6	66
1.00	3.3	33
2.00	1.6	17

(4) Filter Distortion

Narrow band interference filters are designed for light at normal incidence. The transmission band will shift for those rays incident at non-normal angles. The magnitude of this effect is proportional to the cosine of the angle of incidence and, therefore, is negligibly small for the angles within about 7^{o} of the normal. The lens focal length and camera-to-scene range were chosen to keep the total field of view within these limits, therefore, avoiding any spectral distortion due to off-axis rays.

(5) Acquisition Time

Data for a single scene must be acquired in a time interval during which there is no significant displacement or change in the shadow patterns in the scene. When the scene is lit by direct solar illumination, the acquisition time is limited by the rate of the earth's rotation. All data should ideally be acquired within the time a shadow boundary shifts by no more than two resolution elements.

Table 1 lists this time duration for resolution elements of 1.45 and 14.5 cm as a function of the spacing between the foreground element which produces the shadow and the shadowed element.

(6) Film Sensitivity

The film must respond over the spectrum from 380 to 700 nm with a sensitivity at each wavelength interval which will produce good image contrast at the available camera f/stop settings and exposure times. Wind conditions in the field will dictate the limitations on exposure times.

(7) Dynamic Range

The film and the subsequent data processing must be able to accommodate the range of radiance levels which are expected to occur in typical scenes.

Figures 6a and 6b depict the spectral reflectance curves for a selection of vegetative and soil formations. For the naturally occurring terrains under consideration in this program, one may expect the reflectances of elements in the scene to be comparable with those shown by the curves in Figure 6a and by curves 5 and 8 in Figure 6b. In any narrow bandwidth the range of reflectivities is on the order of 10:1, with an overall dynamic range over the entire visible spectrum of about 50:1. Thus a dynamic range of two orders of magnitude (100:1) is required.

Any unusual highlights which may appear in a scene due, for example, to specular reflection from a surface, might exceed the dynamic range of the film. However, such highlights are very specific to a particular condition of sun angle and orientation of the scene and may be considered as non-typical.

(8) Photographic Nonlinearity

The relationship between the level of illumination on photographic film and transmission density of the developed transparency is not a linear one and, in addition, is highly dependent on the development process. For this reason, five targets with known levels of reflectance were placed in the scene to serve as a calibration reference. The time and aperture settings used during film exposure were chosen to ensure[7] that the average scene radiance produces a film density in the middle of the linear region of the Density-Exposure (gamma) curve.

A calibration relating transmission density to spectral reflectance is obtained for each exposure, based on the known spectral reflectivies of each reflectance target and the measured transmission density of the target images on the transparency. The spectral reflectance of each resolution element in the scene is then obtained from the calibration once the density of the resolution element is known (See Appendix A).

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[7] J. R. Goldgraben and B. Engelberg, Procedures for the Acquisition and Analysis of Terrain Data for Camouflage Design, Volume 2, Manual for Photographic Data Acquisition and Film Digitization, Decilog, Inc., Melville, NY, March 1981.

The photographic image of each reflectance target encompasses an area of at least two resolution elements by two resolution elements to avoid the introduction of calibration errors resulting from MTF losses in the film.

c. Data Acquisition Equipment

The following is a list of equipment used in a photographic acquisition and digitization process.

CAMERA: 35 mm camera with 28 mm f/4 lens
A cable release or equivalent is needed.

FILM: Kodak Linagraph Shellburst (No. 2476).

FILTERS: 3 cavity 0.75-inch diameter interference filters with nominal bandwidth (at half power point) of about 11 nm. Central wavelengths at 20-nm intervals from 380 nm up to and including 700 nm.

FILTER HOLDERS: For each camera and radiometer.

RADIOMETER: With an irradiance probe, a detector field of view of approximately 4° (a field of view limiter may be necessary), and a sensitivity of at least 0.001 mw/cm^2.

REFLECTANCE STANDARDS: Lambertian Diffuse reflectors, 6" x 6" with nominal reflectances of 78%, 25%, 14%, 7%, and 2%.

SECOND CAMERA: With color film.

TRIPODS: For first camera and radiometer.

Specifications and data for the equipment are included in Appendix C.

TABLE 2

SCENE LISTING

Site	Scene Description	Scene Number	Season[1]	Sky Condition[2]	Resoluti
I	Deciduous with brush	3	D	C	N
I	Deciduous with brush	4	D	C	F
I	Deciduous with brush	9	D	O	F
I	Deciduous with brush	15	V	C	F
I	Deciduous with brush	21	V	O	F
II	Deciduous with brush	14	V	C	N
II	Deciduous with brush	16	V	C	N
III	Deciduous with brush	12	V	O	N
III	Deciduous with brush	18	V	C	N
IV	Coniferous	7	D	C	F
IV	Coniferous	13	V	C	F
IV	Coniferous	20	V	O	F
V	Deciduous with coniferous	5	D	C	F
V	Deciduous with coniferous	6	D	O	F
VI	Mixed brush	19	V	O	N
VII	Fruit Orchard	11	D	C	N
VIII	Wild fruit trees	17	V	C	N
IX	Under deciduous canopy	8	D	-	N

[1] D: dormant; V: verdent

[2] C: clear; O: overcast

[3] N: near (1.45 cm/pixel); F: far (1.45 cm/pixel)

d. <u>Selection of Terrain Types</u>

Terrain data was acquired for scene typical of temperate areas, similar to those commonly found in Central Europe (for example, West and East Germany). It is also desirable that the scenes be typical of those which would be used in tactical operations. Despite the increase in "suburbanization" of this area, with the consequent increased likelihood of military operations in builtup areas, the initial data acquisition efforts utilized vegetative terrains to demonstrate the camouflage design methodology. The scenes chosen were typical of Central European vegetative terrains.

A review of topographic maps of Germany reveals that the preponderance of vegetation is coniferous, deciduous, and mixed forests. In addition, trees and brush, and orchards are fairly common.

All of data were taken on Long Island, New York, in areas where undisturbed access in both summer and winter was available. Table 2 lists the scenes for which data have been acquired.

e. <u>Description of Software Modules</u>

The computer software is divided into four main programs:
ETLREAD, DATAPREP, ANALYSIS, and SYMPLOT

ETLREAD reads the files on the magnetic tape output of the film digitizer, converts the recorded data into units of optical density, and stores the results on disk files (Called ETL FILES).

DATAPREP generates the basic data files (called DATA BASE FILES) for each terrain scene. These files contain the reflectance values at each of the photographed wavelength intervals for each scene pixel within a user specified rectangular region. The data files can accommodate reflectance values for seventeen wavelength intervals which are presumed to be equally spaced at 20-nm

increments between 380 and 700 nm. DATAPREP will determine the record and wavelength intervals for which data are available. A user inputted description of the scene and a scale factor are also placed into the basic data files.

ANALYSIS performs all computations required to generate a color domain map of the scene. CIELAB coordinates are computed for scene pixels based on a user inputted spectral irradiance and on the reflectance data contained in the basic DATA BASE FILES. The program will cluster the CIELAB values down to 3, 4, or 5 best color domains or use domain CIELAB values inputted by the user. Scene pixels are then assigned to the color domains whose CIELAB coordinates are closest to its own computed CIELAB value. Each color domain is also assigned a spectral reflectance curve from the scene pixel whose CIELAB coordinates are closest to the domain coordinates. A program option combines data from adjacent pixels to simulate the effect of viewing distance on the spatial detail and colors perceived in the scene. The program generates a file (called CALCOMP FILE) containing the pixel domain assignments, spectral reflectance data for each domain, and descriptive header information and other parameters used in the analysis.

SYMPLOT uses the CALCOMP FILE created in ANALYSIS to write a tape that will drive the CALCOMP plotter. Each color domain is assigned a symbol, and the symbol representing the appropriate pixel domain assignment is then plotted at each pixel location.

Details on algorithms, flow charts, program listings, inputs, and sample outputs for each program module are presented.[8]

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[8] J. R. Goldgraben and B. Engelberg, Procedures for the Acquisition and Analysis of Terrain Data for Camouflage Design, Volume 1, Software Manual, Decilog, Inc., Melville, NY, March 1981.

f. Technical Considerations in the Software Design

The primary requirements for the data processing and analysis software were established to keep the core storage requirements at any time below 42k and to avoid excessive computation times. This section describes those computational algorithms and data handling procedures which were implemented to meet these requirements.

As described in Section 2e, clustering of the pixel CIELAB values to form color domains is performed in a two step process: histogramming and Euclidean distance clustering. Clustering by the Euclidean distance algorithm[9] is an optimal process but requires an enormous number of computations and logical operations. The histogram algorithm, therefore, is used as a first step to greatly reduce the number of CIELAB clusters that must be handled by the Euclidean algorithm.

The number of distances N_D between a set of N_i CIELAB data point or clusters is given by

$$N_D = \frac{N_i}{2} (N_i - 1)$$

In a near scene, for example, each of the 19,600 pixels could have a unique CIELAB coordinate. The first iteration of a Euclidean clustering algorithm could therefore require the computation of 192,070,200 distances (N_i = 19,600) and a logical comparison of all of these distances to seek a minimum. At each succeeding iteration the two closest clusters are combined into one. This leaves $(N_i - 1)$ new clusters and requies the computation of $\frac{(N_i - 1)}{2} (N_i - 2)$ new distances and the logical comparison of $\frac{(N_i - 1)}{2} (N_i - 2)$ distance values. The need to reduce the initial number of CIELAB clusters is evident.

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[9] J. R. Goldgraben and B. Engelberg, Procedures for the Acquisition and Analysis of Terrain Data for Camouflage Design, Volume 2, Manual for Photographic Data Acquisition and Film Digitization, Decilog, Inc., Melville, NY, March 1981.

The histogram clustering is, however, not an optimal process: it does not necessarily produce clusters with minimum dispersion. As described in Section 4b of the report, a third clustering step is recommended to optimize the final color domain clustering. This process would remove most of the bias introduced by the histogram clustering at little additional cost in computation time.

It appears, from a limited study of the terrain data, that the bias introduced by the histogram clustering is not significant. Further study on this aspect of the technique is, however, recommended.

A second feature which was implemented to reduce core storage requirements is the limitation on the number (NPIX) of occupied cells in the CIELAB space (See Section 2e above). Core storage increases by about 11k for each 1000-cell increment in NPIX. The 1000-cell limit specified in the software appears adequate for the terrain analysis purposes.

Core requirements have also been minimized by the judicious assignment of arrays to common blocks and by processing the scene data one row at a time. Data is stored by rows on disk files with data from each row constituting one record.

FIGURE 7. Digitizing Pattern on Camouflage Cloth

3. VALIDATION

A limited validation of the data acquisition and processing techniques was performed using a piece of four-color woodland camouflage cloth as the scene. Figure 7 shows a portion of the digitizing grid overlayed on a section of the cloth. The aperture size and spacing are shown to scale. The scene area selected for processing contained 1131 pixels (29 x 39).

A small sampling of the spectral data generated for the camouflage cloth has been compared with data obtained by direct spectrographic analysis of the cloth. The latter measurements were made by the Countersurveillance section at NLABS.

Figures 8 through 11 compare the reflectance values obtained by the terrain analysis technique with reflectance curves obtained by NLABS. The terrain data was obtained from a sample of 30 pixels selected at random from the computer printout. The reflectance curve for each pixel was compared to the NLABS data and assigned to one of the pattern colors. Of the thirty pixels, three were categorized as woodland light green, nine as dark green, nine as brown, and six as black. The reflectance curves of three pixels did not match any of the colors and were eliminated.

Table 3 lists the CIELAB values of the camouflage cloth obtained by clustering of the 1131 pixels. The tolerances shown on the NLABS data represent one standard deviation (from three measurements).

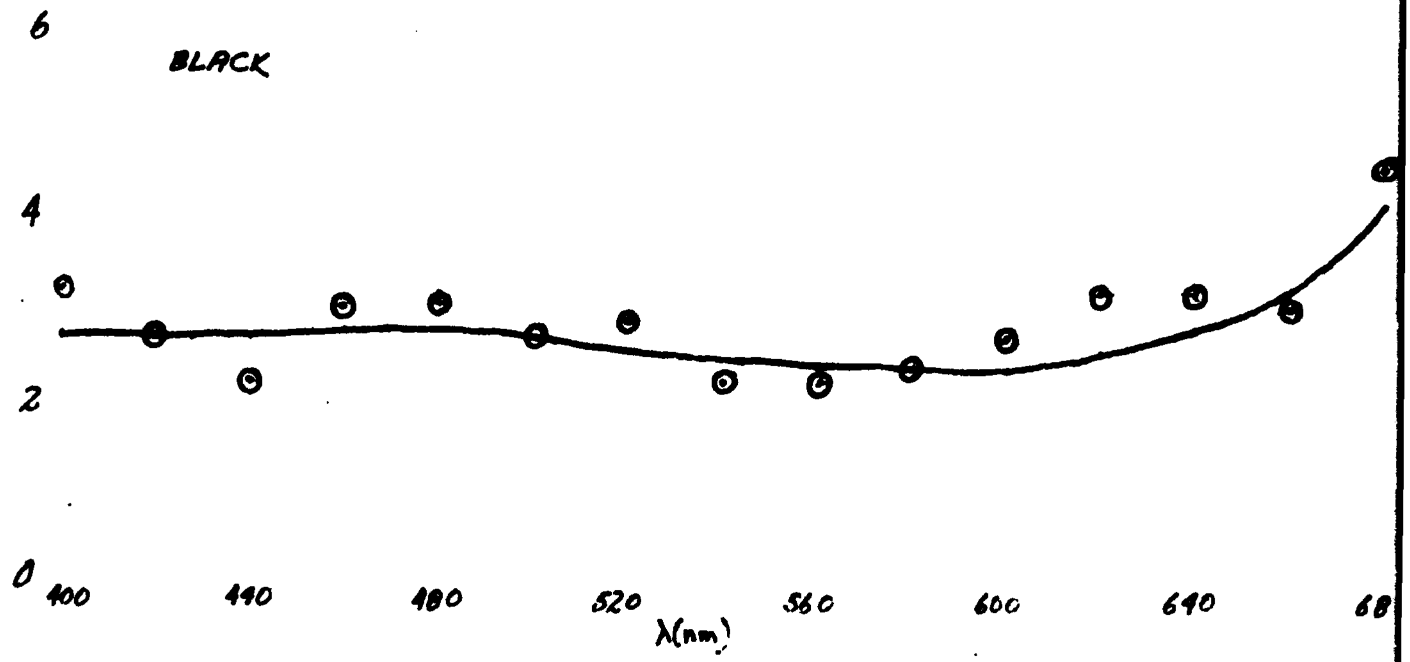

FIGURE 8. Comparison of Spectral Data for Woodland Camouflage-Black
NLABS Measurements: ——; Terrain Analysis Data: θ

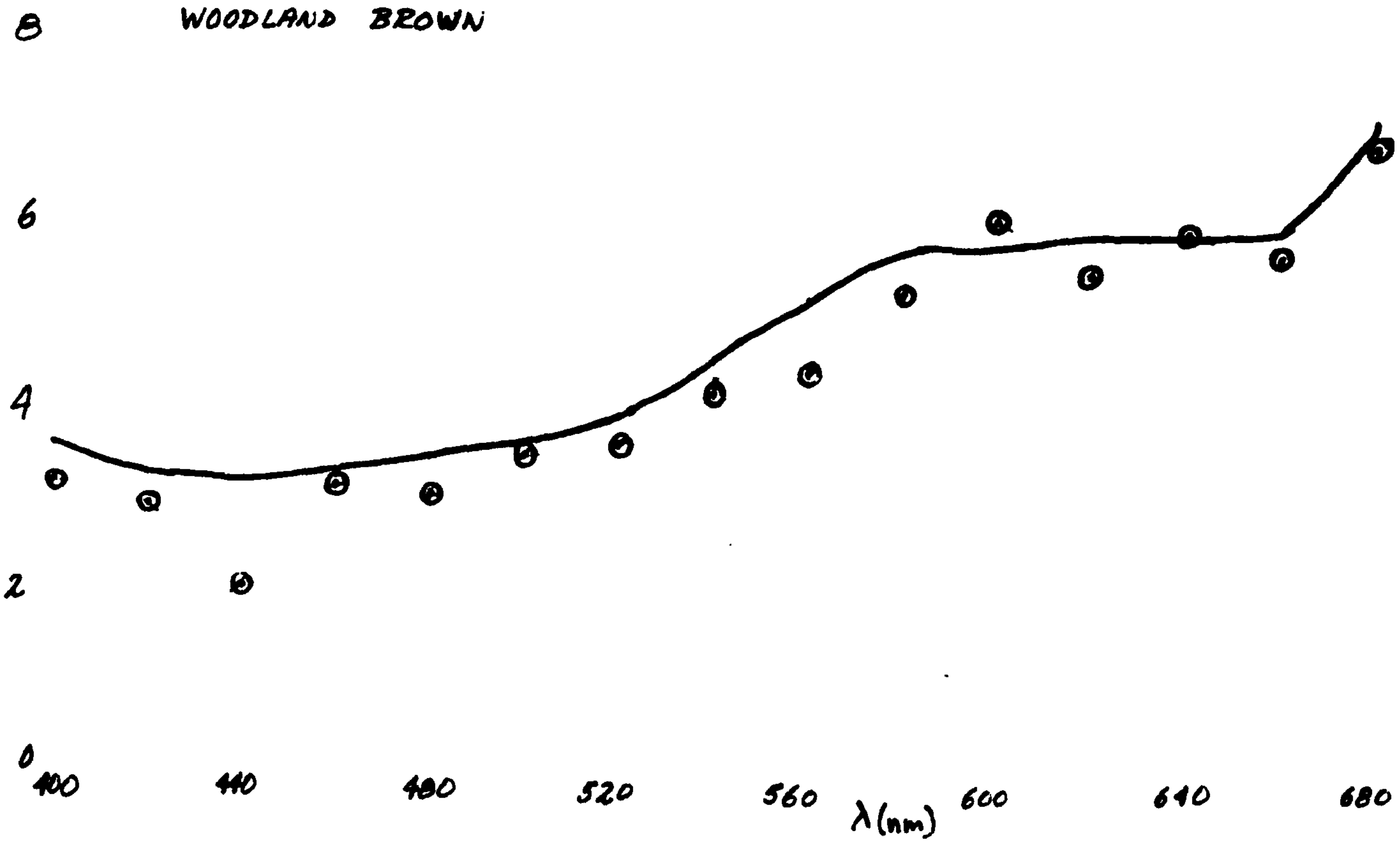

FIGURE 9. Comparison of Spectral Data for Woodland Camouflage-Brown
NLABS Measurements: ——; Terrain Analysis Data: θ

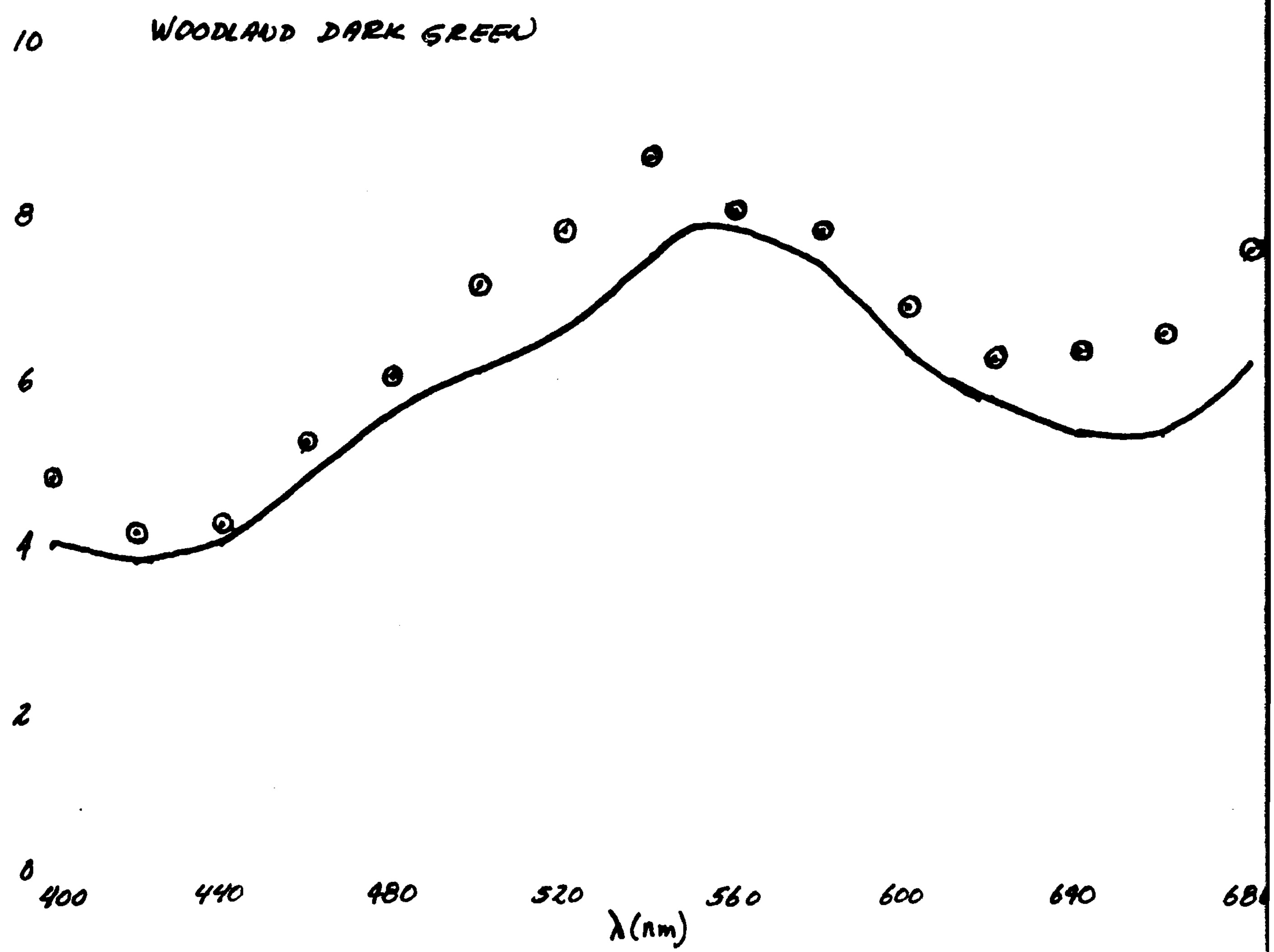

FIGURE 10. Comparison of Spectral Data for Woodland Camouflage-Dark Green
NLABS Measurements: ——; Terrain Analysis Data: θ

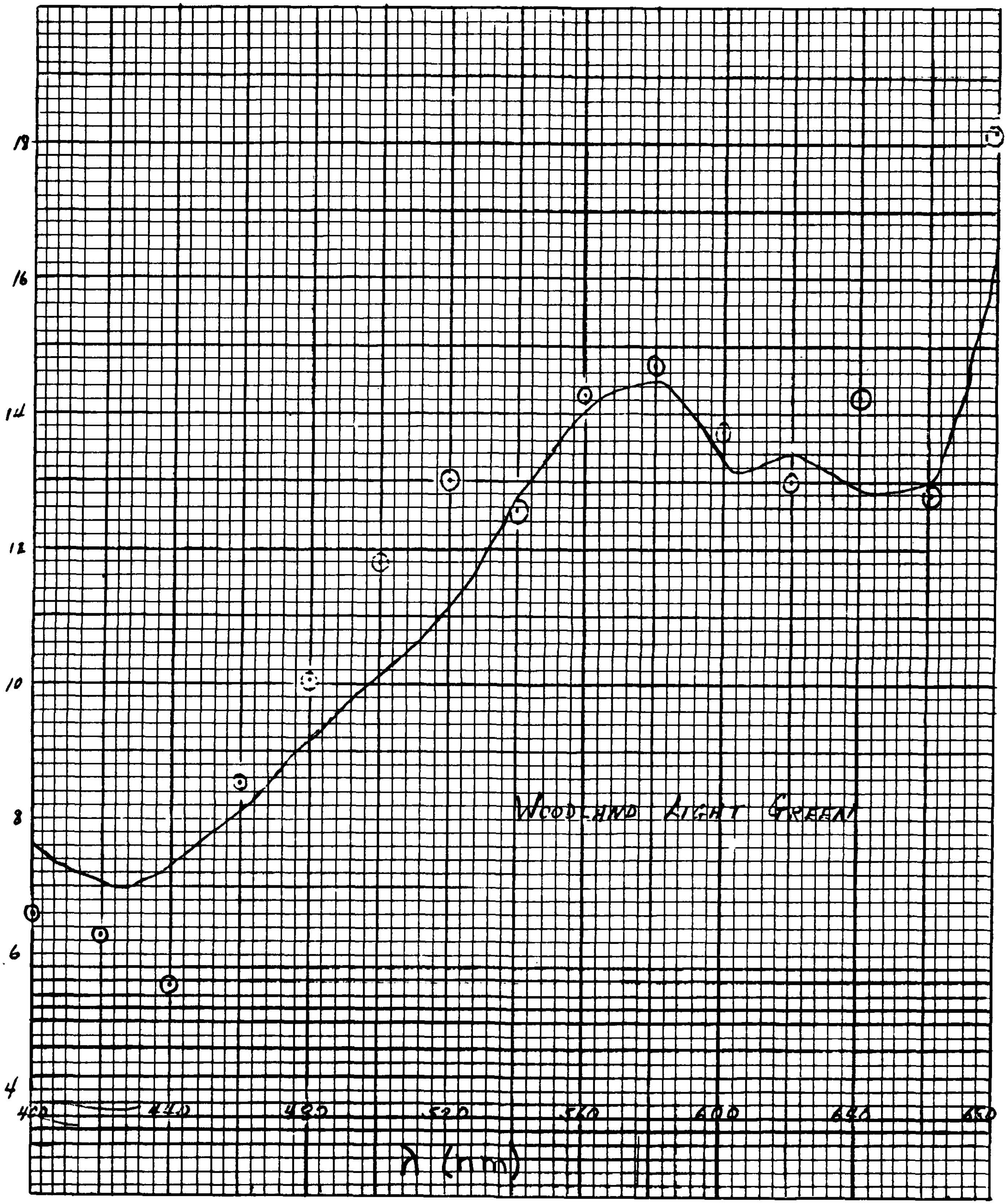

FIGURE 11. Comparison of Spectral Data for Woodland Camouflage-Light Green
NLABS Measurements:——— ; Terrain Analysis Data: ⊙

TABLE 3

Comparison of CIELAB Coordinates of Color Domains on Camouflage Cloth

Source: D_{65}

Data Source	Sample Size	L^*	a^*	b^*	ΔE
Brown:					
NLABS	3	26.46±.27	3.15±.12	9.06±.21	---
Random Sample	9	25.27	3.82	10.82	2.29
Cluster Sample	56	25.22	3.36	9.93	1.5
Dk. Green:					
NLABS	3	31.67±.48	-6.54±.2	10.05±.27	---
Random Sample	9	33.11	-7.69	10.08	1.83
Cluster Sample	10	31.99	-10.06	12.00	4.0
Lt. Green:					
NLABS	3	42.22±.15	-1.7±.12	14.47±.12	---
Random Sample	4	41.99	1.00	15.20	2.95
Cluster Sample	--	--	--	--	--
Black:					
NLABS	3	16.93±.76	1.14±.19	-2.28±.37	---
Random Sample	6	17.99	-1.00	-1.66	1.95
Cluster Sample	--	--	--	--	--

TABLE 4 TERRAIN ANALYSIS OF CAMOUFLAGE CLOTH
(FOUR COLOR WOODLAND CLOTH SCENE 10)

1131 Pixels

NSWTCH = 9

CASE	DENSITY	ITHRSH	INTERV	DOMAIN #	NUMBER	L*	a*	b*	VAR	PIXEL FRACTION
1	3.000	3	1	1	27	32.12	-9.84	12.00	0.613	0.18
				2	25	41.99	-4.12	15.97	0.922	
				3	91	25.17	3.86	9.92	1.125	
				4	55	24.94	2.32	9.76	1.155	
2	0.375	3	2	1	47	18.76	-0.07	0.51	3.85	0.40
				2	63	31.19	-9.07	11.53	3.00	
				3	51	41.30	-4.23	15.26	3.22	
				4	290	25.14	3.31	9.88	5.28	
3	0.111	3	3	1	82	18.10	0.33	-0.01	5.73	0.72
				2	356	24.79	3.10	9.20	10.78	
				3	218	31.51	-8.05	12.10	13.71	
				4	160	41.17	-3.93	15.66	13.24	
4	5.000	5	1	1	40	24.50	3.92	9.73	0.66	0.08
				2	51	25.69	3.81	10.07	0.81	
5	0.625	5	2	1	63	43.45	-4.28	16.47	2.75	0.35
				2	86	31.57	-8.60	12.17	2.30	
				3	40	41.14	-3.62	15.69	2.10	
				4	203	24.78	3.85	9.62	2.69	

TABLE 4 TERRAIN ANALYSIS OF CAMOUFLAGE CLOTH (Cont'd)
(FOUR COLOR WOODLAND CLOTH SCENE 10)

1131 Pixels

NSWTCH = 9

CASE	DENSITY	ITHRSH	INTERV	DOMAIN #	NUMBER	L*	a*	b*	VAR	PIXEL FRACTION
6	0.185	5	3	1	77	18.19	0.16	0.12	4.80	0.56
				2	93	42.92	-4.85	17.01	4.93	
				3	167	30.82	-8.04	12.14	8.43	
				4	294	24.83	3.74	9.58	6.96	
7	10.000	10	1	1	23	25.08	3.93	9.88	0.24	0.06
				2	10	31.99	-10.06	12.00	0.30	
				3	10	26.11	2.97	10.90	0.18	
				4	23	24.98	2.95	9.57	0.44	
8	1.250	10	2	1	34	17.70	0.37	-0.26	1.54	0.33
				2	46	41.88	-3.36	15.38	1.71	
				3	92	31.40	-9.06	12.17	2.30	
				4	196	24.93	3.74	9.74	3.36	
9	0.370	10	3	1	47	18.76	-0.07	0.51	3.85	0.44
				2	63	31.19	-9.07	11.53	3.00	
				3	97	42.35	-4.40	15.74	4.38	
				4	290	25.14	3.31	9.88	5.28	

Table 4 summarizes the results of clustering the camouflage sample down to 4 domains with different combinations of clustering parameters. Column headings are defined as follows:

DENSTY: The Threshold density required to establish a domain in L*a*b* space. $\text{DENSTY} = \frac{\text{ITHRSH}}{(\text{INTERV})^3}$

ITHRSH: is the minimum number of pixels required to establish a domain in the histogram algorithm for a cell of side length INTERV

INTERV: is the initial size of the cubical histogram cells in L*a*b* space

DOMAIN NO: a domain assignment number

NUMBER: Number of pixels assigned to domain

L*a*b*: Centroidal CIELAB value of pixels assigned to domain

NSWTCH: maximum number of domains at which clustering shifts to Euclidean algorithm

FRACTION: fraction of total number of pixels which were assigned to domains

Several observations may be made concerning the data presented in Table 4.

a. One can easily correlate a domain number with a color domain by use of the NLABS data in Table 3.

b. The dispersion of the pixel CIELAB values is high (Case 3). A separate analysis of the CIELAB distribution shows diffuse clusters centered at the four primary CIELAB values with a sparser background distribution joining the main clusters. This background arises primarily from pixels which in the digitizing process fell across domain boundaries. The thresholding parameters should be selected to filter out this background. Observe in Case 1 that a threshold density of 3 identifies clusters with pixels close to the domain centroids (variance is low). This density only included 18% of the total of 1131 pixels.

c. In Case 7 the density was set too high and the clustering picked up only two domains. (Note that domain 1, 3, 4 in Case 7 are the same domain).

   A similar result occurred with Case 4.

d. Case 3, still at a high density threshold, did not pick up the black domain (Domain 3 and 4 are both brown).

4. COMMENTS AND RECOMMENDATIONS

a. Data Acquisition

The photographic data acquisition process has proven to be an adequate technique for terrain data acquisition. Its primary shortcoming is the time required to obtain and digitize seventeen scene exposures. The seventeen photographs can be taken in 25 to 35 minutes and digitized in a little over 3 hours (about 10 minutes per exposure). Studies should be run to determine the extent to which the number of exposures can be reduced. This can be done with the existing data and with a slight modification in the code of the Analysis Program.

b. Optimization of Clustering

In the existing data analysis program, a histogram algorithm (HIST) is used as a first step in the clustering of the CIELAB values of the scene pixels. This algorithm is highly efficient and greatly reduces the number of computations that must be performed by the Euclidean clustering algorithm (GEOM). This histogram process is not, however, an optimal process and the CIELAB coordinates of the final color domains can be influenced by the color coordinate increments used in the histogramming and by the number of intermediate clusters which exist when the clustering process switches from HIST to GEOM. The increment levels and number of intermediate domains are user-specified.

An optimal clustering is one which minimizes the total variance or squared vector distance between all pixels and their respective domain centroids in the CIELAB color coordinate system. The histogram process can produce clusters which are not optimal. The Euclidean algorithm which follows as a second step takes the histogram clusters and further clusters these into the final number of color domains. While the Euclidean algorithm is optimal, any bias introduced in the histogram process is propagated through the Euclidean clustering process.

If the number of intermediate clusters to be created by histogramming is set at a value significantly greater than the final desired number of domains, the bias introduced should be very small. It would be necessary, however, to run a series of parametric studies to give the user some guidance in setting the clustering parameters. This guidance would, however, be only of a qualitative nature and some uncertainties would always exist.

It is recommended, therefore, that an optimization routine be added to the existing color domain clustering process. The CIELAB values assigned to the 3-, 4-, or 5-color domains by the existing histogram and Euclidean algorithms will be inputted into the optimization routine which will readjust the CIELAB centroid values using a nearest means iterative optimization algorithm. The algorithm will eliminate most of the bias that may have been introduced in the histogram clustering and will thereby make the spectral and spatial characteristics of the final color domains independent of the user's choice of clustering parameters.

With the optimization feature, the user-specified clustering paramenters will only influence the running time of the computation. This modification should be made prior to running sensitivity and parameter studies on the data.

c. <u>Parametric and Sensitivity Studies</u>

A series of parametric and sensitivity studies should be run to provide data as guidance on the use of this terrain analysis methodology. The objectives of the studies would be:

(1) To determine the extent to which the domain CIELAB values and patterns are affected by the
   - (a) number of wavelengths used in the analysis*
   - (b) illumination spectrum
   - (c) number of domains selected

* A slight modification of the code of ANALYSIS is needed for this.

(2) To determine variability in CIELAB values and patterns from scene to scene.

(3) To determine the effect of clustering paramters on program running time.

d. Individual Domain Mapping

In the current version of SYMPLOT, all of the color domains are mapped onto one plot. While this allows the user to obtain a reconstructed image of a scene in 3-, 4-, or 5-color domains, it is not an effective way to display the shapes and distribution of the individual color domains. It is therefore recommended that a small revision of the code of SYMPLOT be made to allow individual color domains to be mapped.

This document reports research undertaken in cooperation with the US Army Natick Research and Development Command under Contract No. DAAK60-79-C-0072 and has been assigned No. NATICK/TR-82/037 in the series of reports approved for publication.

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5. Goldgraben, J. R. and B. Engelberg, Procedures for the Acquisition and Analysis of Terrain Data for Camouflage Design, Volume 1, Software Manual, Decilog, Inc., Melville, NY, March 1981.

6. Goldgraben, J. R. and B. Engelberg, Procedures for the Acquisition and Analysis of Terrain Data for Camouflage Design, Volume 2, Manual for Photographic Data Acquisition and Film Digitization, Decilog, Inc., Melville, NY, March 1981.

APPENDICES

APPENDIX A

Theory of Photographic Data Acquisition

The characterization of natural terrain in terms of uniform color domains requires a data base containing spectral reflectance values for each pixel in the scene. This appendix describes the theoretical basis for the photographic data acquisition process.

It is first important to clearly define what is meant by reflectivity, since two different interpretations are possible. In the world of physics, reflectivity is defined as the ratio of the radiance reflected from a surface to the irradiance incident on that same surface. This quantity represents the inherent reflectivity of a surface. In photography and in visual processes, however, one generally interprets reflectivity to be the ratio of the radiance measured from a point in the scene to the irradiance incident on the total scene. This so-called photographer's reflectance is dependent, not only on the inherent reflectivity of each structural element in the scene, but also on the shadows that result from multiple reflections and indirect illumination and on the orientation of the surfaces with respect to the viewer's line of sight. A scene created only from inherent reflectivity would be more homogeneous and contain less radiance structure than scenes in the real world. In camouflage design, the shadows and varying radiance structure in the scene due to multiple reflections and surface orientations must be considered. The reflectivity data base must, therefore, be obtained according to the photographer's definition.

Figure A-1 depicts the nature of a scene structure based on the photographer's reflectivity. A side view of an idealized natural scene is shown in (a) with two scene elements; a foreground surface A and a partially hidden rear surface B. Under illumination with a spectral radiance $S_o(\lambda)$ at each wavelength, λ , the surfaces will emit a spectral radiance $H(\lambda)$ due to the reflected illumination. Note that two levels of radiance are emitted

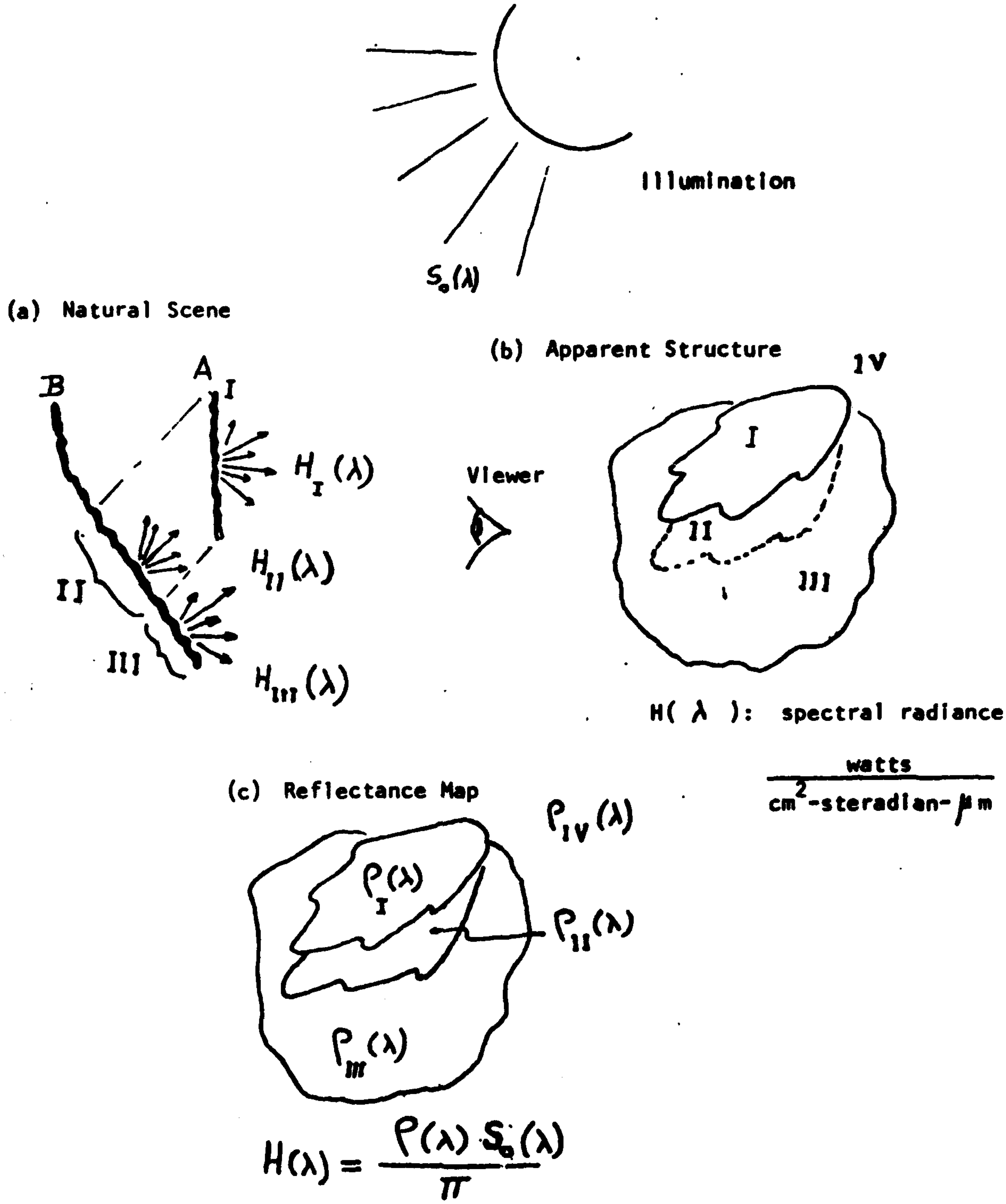


FIGURE A-1. Scene Characterization Using "Photographer's" Reflectance

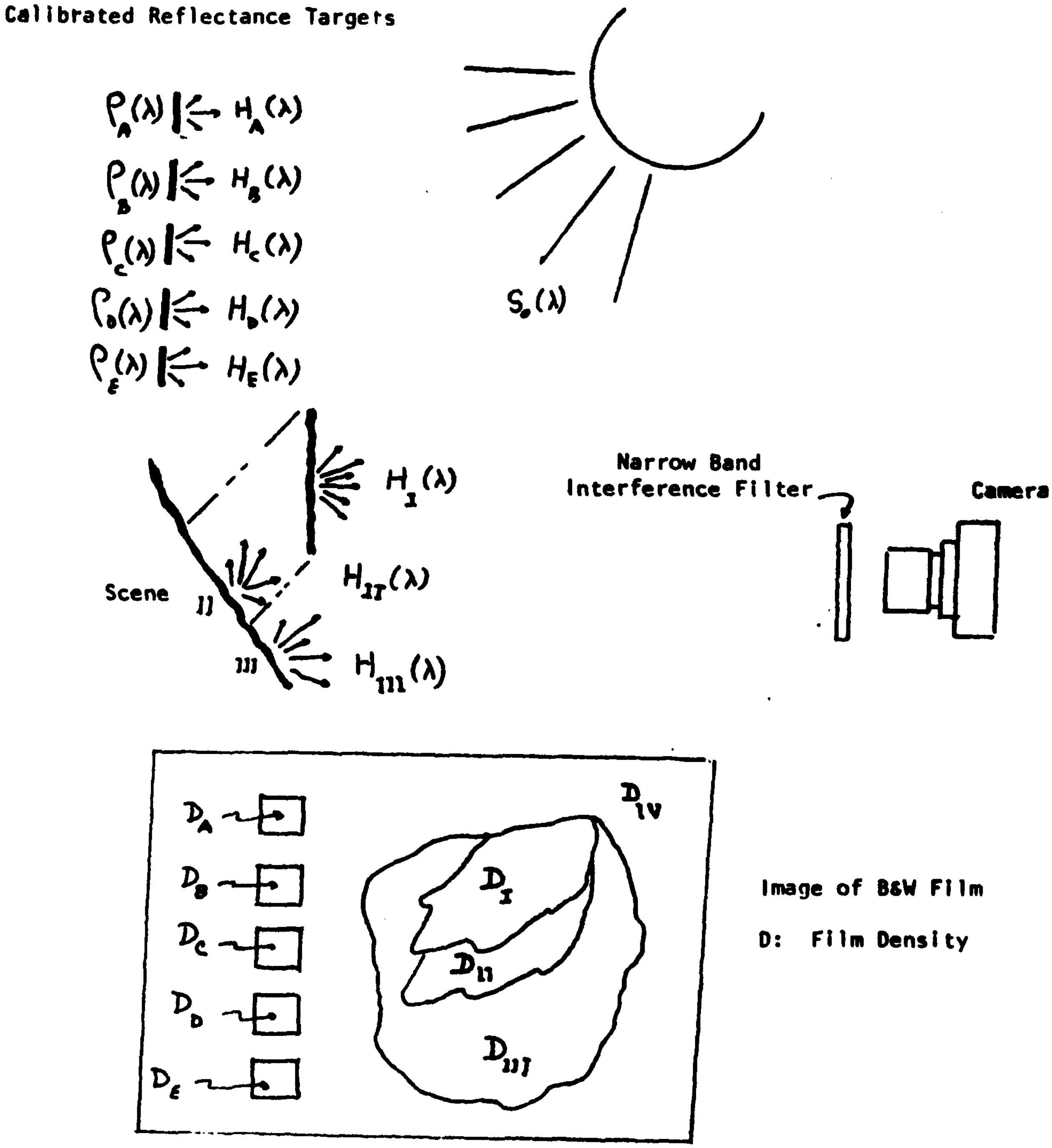


FIGURE A-2. Photographic Data Acquisition

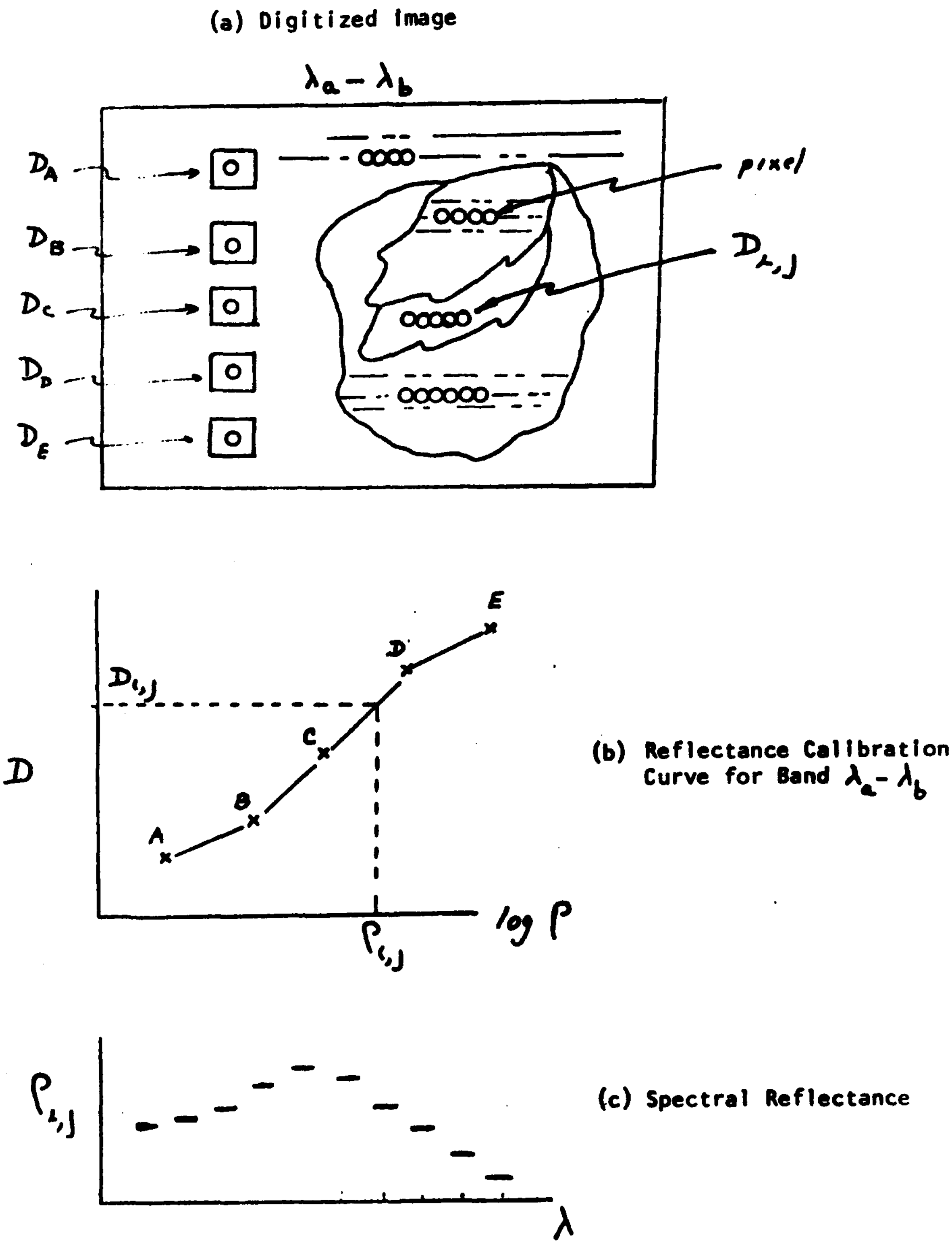


FIGURE A-3. Film Digitization and Reflectance Calibration

from surface B; one ($H_{II}(\lambda)$) from the region in shadow (II) and the other ($H_{III}(\lambda)$) from the region in direct illumination (III). The apparent structure of the scene as perceived by a viewer looking through a filter that transmits only in a narrow band of the spectrum might therefore appear as in (b). The viewer would sense the variations in spectral radiance in the particular wavelength band.

The photographer's reflectance $\rho(\lambda)$ at each wavelength λ is defined as follows for each scene pixel, i

$$\rho(\lambda) = \frac{H_i(\lambda)}{S_{o_i}(\lambda)} \tag{A-1}$$

A photographer's reflectance map of the hypothetical scene would therefore appear as shown in (c). Observe that the reflectance mapping in (c) is identical to the radiance mapping in (b).

The reflectivity calculated from equation (A-1) for one illuminant may be used to determine the radiant distribution over the scene for any other illuminant. The irradiance of the illuminant is multiplied by the value of photographer's reflectivity for each pixel at each wavelength interval.

In order to fully characterize the inherent spectral and spatial properties of a scene, one must determine the mapping of photographer's reflectivity for many wavelength bands over the wavelength spectrum of interest.

Figure A-2 depicts the photographic data acquisition process for obtaining reflectance data. Each scene is photographed through a narrow band optical filter using black and white film. A series of diffuse reflectance targets each with a different shade of gray is placed in the scene and appears in picture. The resulting photograph (in this case, a negative transparency) would appear as shown. The optical density D, at each point in the image is proportional to the radiance emitted from the corresponding object point in

the scene. Thus the transparency represents a radiance map of the scene, and since the radiance, H, is proportional to reflectivity (Equation A-1), the transparency represents a reflectance map of the scene over the narrow wavelength interval transmitted by the filter. A series of transparencies produced by a series of filters each transmitting over a different narrow band of the spectrum provides all of the required data. The reflectance standards provide the specific calibration between film density and reflectivity at each wavelength.

Figure A-3 depicts the digitization process and conversion of film density values to reflectivities using the reflectance target data. The digitization produces arrays of density values $D_{i,j}$ for each scene pixel. The density values D_A, D_B, etc. at the center of each reflectance target is also measured. The target densities at the wavelength interval of the exposure and the known reflectance of each target at the same wavelength are used to form a calibration curve. The calibration curve is best formulated, as shown in Figure A-3(b), in terms of film density versus $\log_{10} \rho$ since the photographic process creates densities which are linearly related to the logarithm of the film exposure. The reflectivity for any scene pixel $D_{i,j}$ is then obtained by linear interpolation of the calibration curve. A full spectral reflectance curve (c) for the pixel is obtained by use of the calibration curve and pixel densities obtained from the other wavelength exposures.

The reflectance targets used in the data acquisistion process are diffuse (Lambertian) surfaces, with nominal reflectance values (in this case the physicist's definition) of 0.05 up to 0.85. A perfectly diffuse surface would have a reflectivity of 1.0. In the conversion of scene densities to photographer's reflectance using the diffuse standards, it is possible to obtain pixel reflectivities greater than unity. Such a result implies that the pixel reflects back more energy to the viewer than a perfectly diffuse surface. Such a condition could occur if the pixel had specular (mirror-like) characteristics, such as water droplets on leaves or very shiny leaf surfaces. Reflectance values greater than unity are therefore retained in the basic data files, since they represent specular highlights in the scene.

APPENDIX B

Identification of Uniform Color Domains by Clustering

After all pixels in a scene have been assigned CIE1976 (L*a*b*) (CIELAB) coordinates, it is desired to identify 3, 4, or 5 colors (color domains) whose CIELAB coordinates represent, in some sense, a best match to the CIELAB values present in the scene. This is achieved by the use of clustering algorithms which partition the pixel CIELAB values into 3, 4, or 5 subgroups. The algorithms utilize the linear property of the CIELAB color space, i.e. it is a uniform color coordinate system where the perceived color-luminance difference between two scene elements is directly proportional to the Euclidean distance between the CIELAB coordinates. Figure B-1 depicts this linear property.

If two pixels, E_1 and E_2, are each described by the set of orthogonal coordinates (L*,a*,b*), the Euclidean distance between them is defined by:

$$((L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2)^{1/2} \qquad \text{(B-1)}$$

In the uniform color space, the perceived color-luminance difference between two points, ΔE^*_{ab}, is directly proportional to the Euclidean distance between them.

The clustering is carried out in a two-stage process, using both an L*a*b* space histogram and a Euclidean distance algorithm. The histogram process is used first to reduce the number of L*a*b* clusters in the scene. The Euclidean distance algorithm is then used to perform the remainder of the clustering.

In the histogramming process, (L*a*b*) space is divided up into cubical cells of equal size as shown in Figure B-2(a). Each cell is numbered and is assigned a centroidal (L*a*b*) value based on the average of the pixel (L*a*b*) values

$$L^* = 116\ (Y/Y_n)^{1/3} - 16$$

$$a^* = 500\left[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}\right]$$

$$b^* = 200\left[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}\right]$$

for

$$X/X_n,\ Y/Y_n,\ Z/Z_n > .01$$

Where X, Y, and Z are the pixel tristimulus and X_n, Y_n, Z_n are the illuminant tristimulus

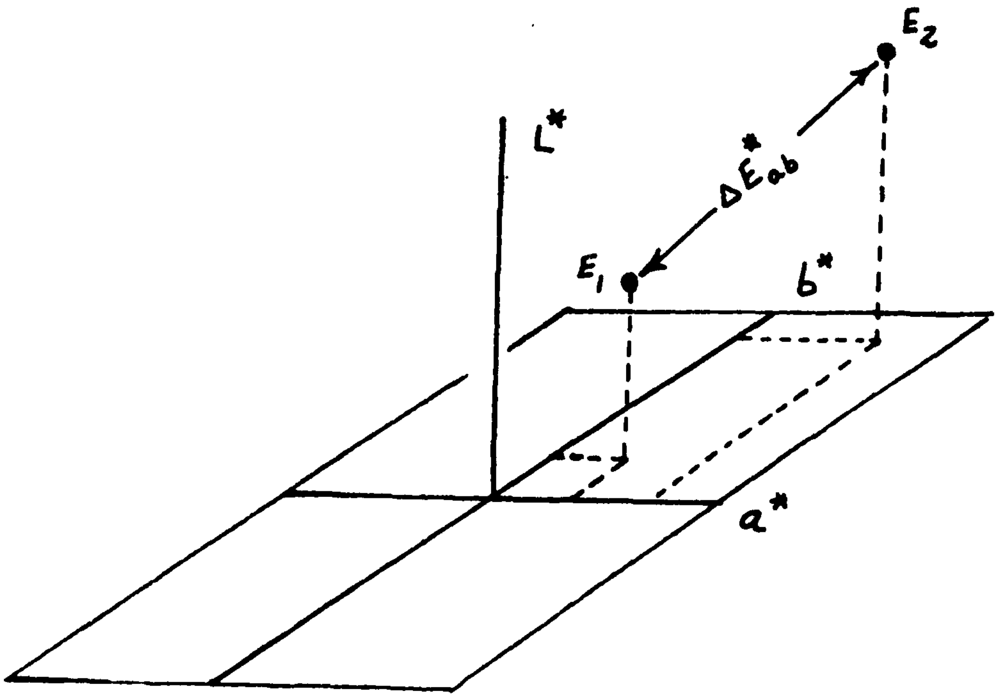


FIGURE B-1. CIE 1976(L*a*b*) Uniform Color Coordinate System (CIELAB)

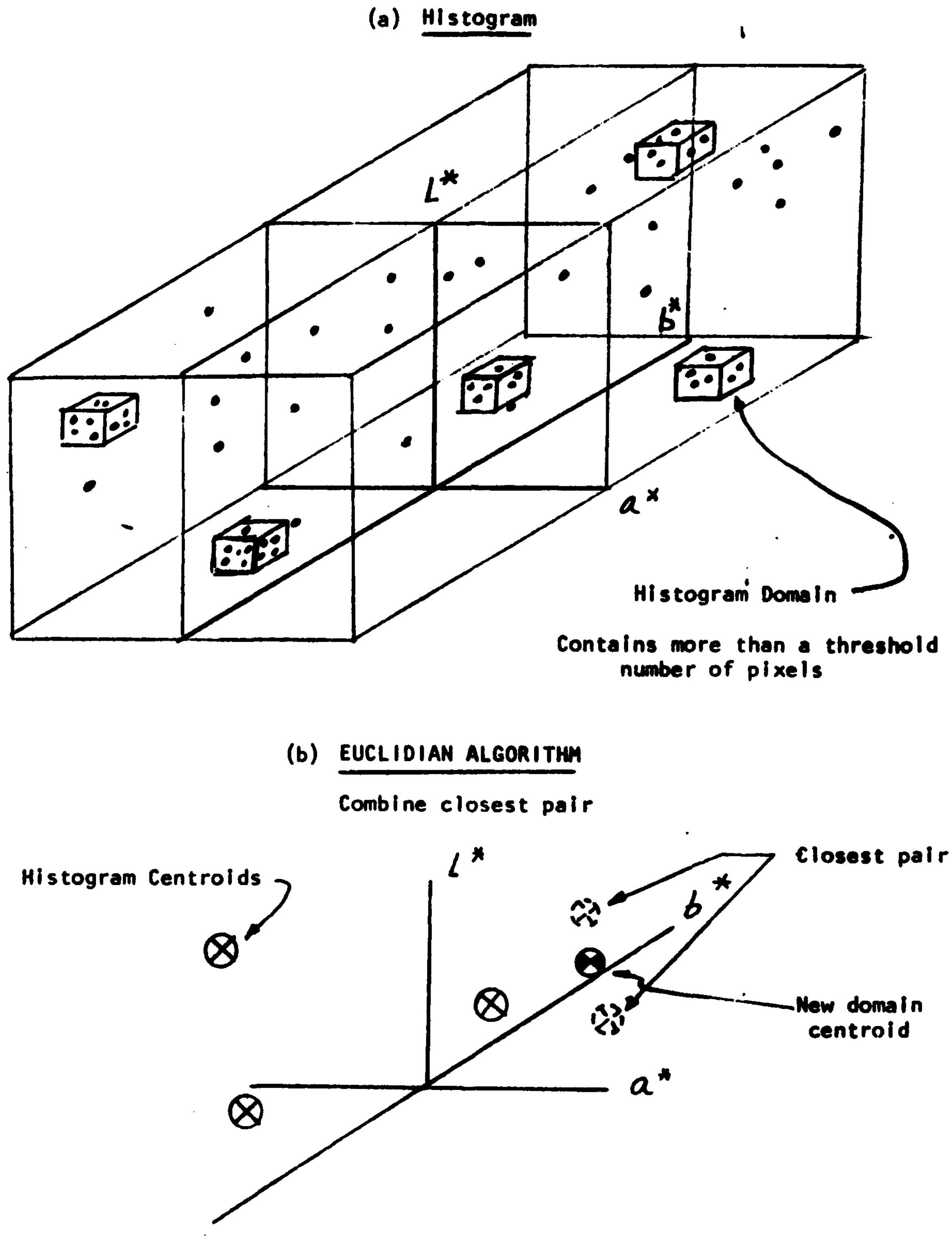


FIGURE B-2. CIELAB Clustering

falling within the volume of the cell. Each cell which contains more than a minimum pixel ($L^*a^*b^*$) density is considered a color domain. The cell size is increased in uniform increments until the number of color domains is reduced to or below some user-specified interim level. When this level is reached, the balance of the clustering to achieve the final number of color domains is performed by a Euclidean distance algorithm.

The Euclidean distance clustering algorithm, for a set of N data points, is performed in the following manner:

(1) Initially, the N data points are considered as N clusters of one point each. The Euclidean distances are computed between each of the N clusters and every other cluster.

(2) The Euclidean distances between all clusters are ordered from smallest to largest.

(3) The two clusters with the smallest Euclidean distance between them are combined to form a new cluster. The position of this cluster in ($L^*a^*b^*$) space is defined as the weighted mean of the positions of the two clusters from which it was formed (See Figure B-2(b)).

(4) The Euclidean distances between this new cluster and all other clusters are calculated.

By repeating Steps 2 through 4 a number of times, J, any number of data points, N, can be reduced to K clusters, where:

$$K = N - J$$

The above procedures will generate K clusters in which the average distances between the individual data points in a cluster and the center of the cluster are minimized.

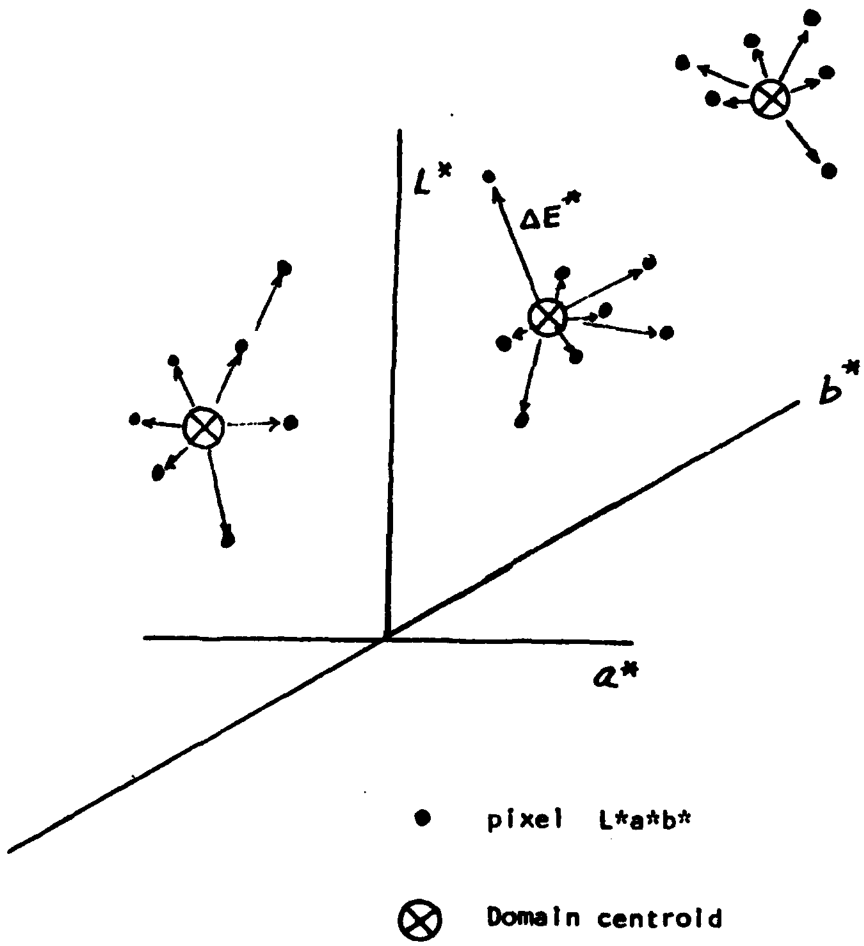


FIGURE B-3 Pixel Domain Assignments

When the clustering process has been completed, and the ($L^*a^*b^*$) coordinates of the desired 3-, 4-, or 5-color domains have been established, each pixel is assigned to the domain with an (L^*,a^*,b^*) centroid closest to its own position, as shown in Figure B-3.

A criterion for evaluating the goodness of fit of the cluster centroids to the terrain data is computed. This is the mean of the squared vector distance (MVD) in CIELAB space between a domain centroid and the pixels assigned to the domain.

APPENDIX C

Equipment Specifications and Calibration Data

Grayco Optical Corp.

200 NO. STRONG AVE., LINDENHURST, N.Y. 11757

516-226-3100
TELEX-640 482

Oct. 24th, 1979

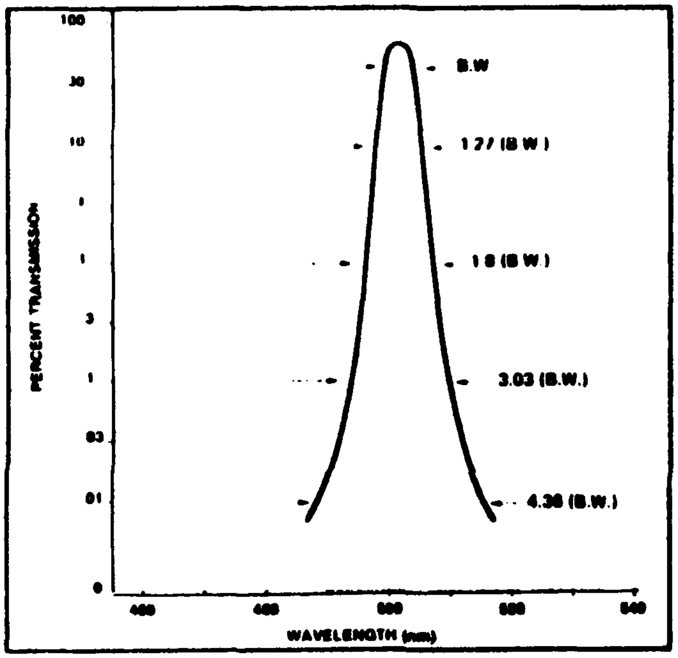
DATA SHEET
CALIBRATION OF DECILOG LENS *

Test Instrument: Beckman Model B Monochrometer

WAVELENGTH	TRANSMITTANCE	
400 NM	67%	
425 NM	80%	
450 NM	84%	
475 NM	84%	
500 NM	85%	
525 NM	85%	
550 NM	84%	
575 NM	84%	
600 NM	85%	
625 NM	(87%)	85
(650 NM)	(59%)	84
(675 NM)	(59%)	83
(700 NM)	(59%)	82
(725 NM)	(55%)	
(750 NM)	(53%)	

* TAMRON - F, 28mm, Ø 52mm f/2.8
No. 602634

FIGURE C-1. Camera Lens Transmission



3 CAVITY FILTER

FIGURE C-2. Filter Transmission Characteristic

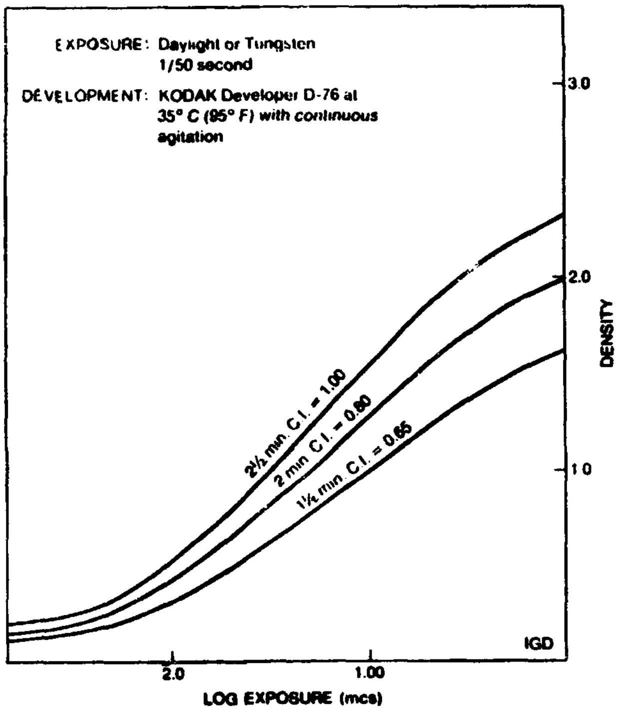
Filter Characteristics

WAVELENGTH (nm)	BANDWIDTH (nm)	PEAK %T MIN.
380.0	11.2	30
400.0	9.0	30
420.0	7.0	45
440.0	7.5	45
460.0	6.8	45
480.0	7.1	45
500.0	7.4	50
520.0	8.2	50
540.0	8.7	50
560.0	9.4	50
580.0	9.8	50
600.0	10.0	50
620.0	10.6	50
640.0	11.3	50
660.0	11.6	50
680.0	11.5	45
700.0	12.3	45

FIGURE C-2. Filter Transmission Characteristic (Cont'd)

Characteristic Curves

KODAK LINAGRAPH SHELLBURST Film 2476 (ESTAR-AH Base)



Characteristic Curves

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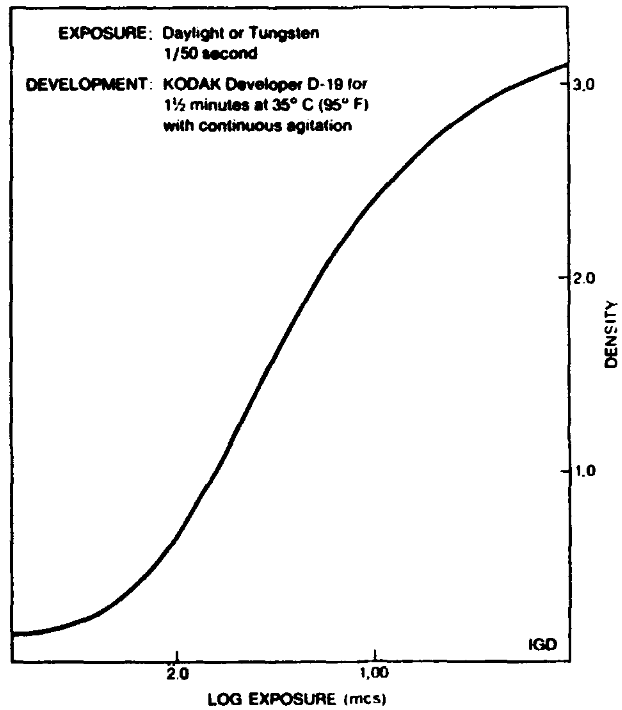


by trial. In these cases, the following adjustments are offered as a guide.

New Condition	Adjustment
The same contrast index with increased Developer D-76 temperature	Increase exposure index up to 60 percent.
Reduced subject contrast	Increase exposure index and develop to a higher contrast index in Developer D-76 or Developer D-19.
Best printing quality with normal subject contrast and normal paper contrast	Decrease exposure index up to 75 percent and reduce development in Developer D-76 to achieve a contrast index of 0.6.
Exposure filters required for special effects	With an unfiltered meter, reduce the exposure index up to 90 percent, as required.

Reciprocity Data: The following chart describes the speed, exposure, and contrast changes over the range of exposure times indicated, with primary development time in KODAK Developer D-19.

	Exposure Time in Seconds								
	10^2	10^1	10^0	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}
Speed*	−75%	−50%	−20%			None			
Exposure†	+2	+1	+½			None			
Contrast‡				None					

*Speed change at a net density of 1.00
†Required exposure adjustment in photographic stops
‡Change in average contrast between net densities of 0.30 and 1.00

Image-Structure Characteristics

This information is based on the primary development recommendation with KODAK Developer D-19.

Resolving Power

Test-Object Contrast 1.6:1	Test-Object Contrast 1000:1
63 lines/mm	160 lines/mm

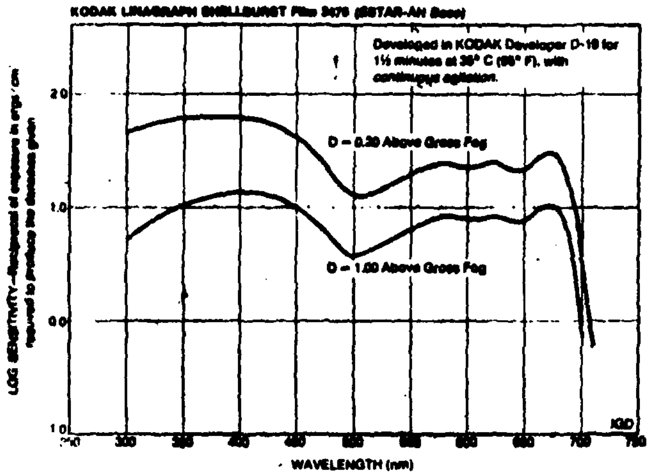
The above values were determined according to a method similar to the one described in ANSI Standard PH2.33-1969, "Method for Determining Resolving Power of Photographic Materials."

Diffuse RMS Granularity: 22

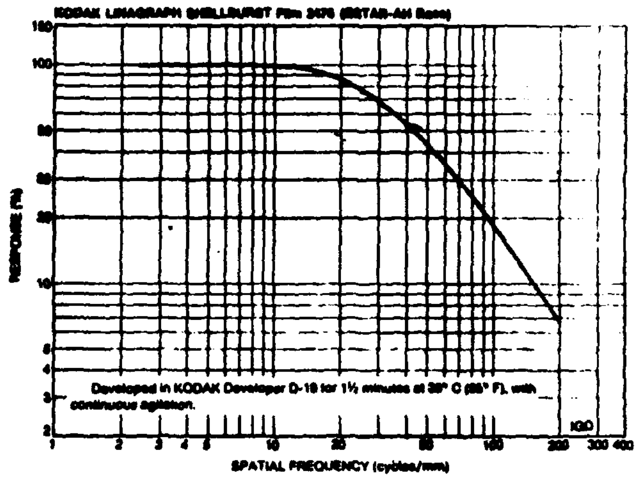
This value represents 1,000 times the standard deviation of density produced by the granular structure of the material when a uniformly exposed and developed sample is scanned with a densitometer calibrated to read American Standard diffuse visual density, and having a circular measuring aperture 48 micrometers in diameter. Granularity is an objective measurement of the spatial variation of sample density that generally correlates with graininess, which is the subjective effect of image nonuniformity upon the observer. Broadly speaking, granularity measurements with the 48-micrometer aperture will indicate the magnitude of the graininess sensation produced by viewing the diffusely illuminated sample with 12× monocular magnification. It should be noted that if the viewing conditions are changed from the specified 12× condition, the published rms values no longer correctly indicate the relative sensations of graininess produced by various samples.

FIGURE C-3. Film Characteristics

Spectral Sensitivity Curves



Modulation Transfer Curve



PROCESSING

...l Processing

The maximum processing temperature for KODAK LINAGRAPH SHELLBURST Film 2476 (ESTAR-AH Base) is 54.5°C (130°F). However, at temperatures above 40.5°C (105°F), conventional processing to fixed speed or contrast offers little saving in development time because fog increases rapidly at the expense of speed and contrast. Consider the development times listed below as starting points and modify them as required for individual equipment, techniques, and requirements. To minimize process nonuniformity at elevated temperatures, use a conventional processing machine rather than rack or tank processing. Processing solution temperatures should be kept within 3°C (5°F) of the developer temperature.

DEVELOP the film with continuous agitation for the following times. The times shown in green are primary development recommendations for this film.

Development Time (in minutes)

KODAK Developer	20°C (68°F)	24°C (75°F)	29.5°C (85°F)	32°C (90°F)	35°C (95°F)	40.5°C (105°F)
D-19*	12	7	3	2	1½	¾
D-76†	7	5½	3½	2¾	2¼	NR

NR—Not Recommended

*Development times at each temperature are to maintain a constant speed at 0.30 above minimum density.

†Development times at each temperature are to maintain a constant contrast index of 0.9 (gamma of about 1.0). Increase exposure index up to 60 percent at higher temperatures.

RINSE the film in KODAK Stop Bath SB-1a or KODAK Indicator Stop Bath for 15 to 30 seconds at 18.5 to 32°C (65 to 90°F) or 10 to 20 seconds at 32 to 40.5°C (90 to 105°F).

FIX the film with frequent agitation as follows:

Fixer	Fixing Time at 18.5 to 32°C (65 to 90°F)	Fixing Time at 32 to 40.5°C (90 to 105°F)
KODAK Fixing Bath F-5 KODAK Fixer KODAK LINAGRAPH Fixer	3 to 5 minutes	2 to 3 minutes
KODAK Rapid Fixer	1½ to 2½ minutes	1 to 1½ minutes

NOTE: For rapid access to data, fix only for the time required for the negative to clear. If the negative is to be preserved, then you must return it to the fixing bath for the times recommended above; then wash and dry it.

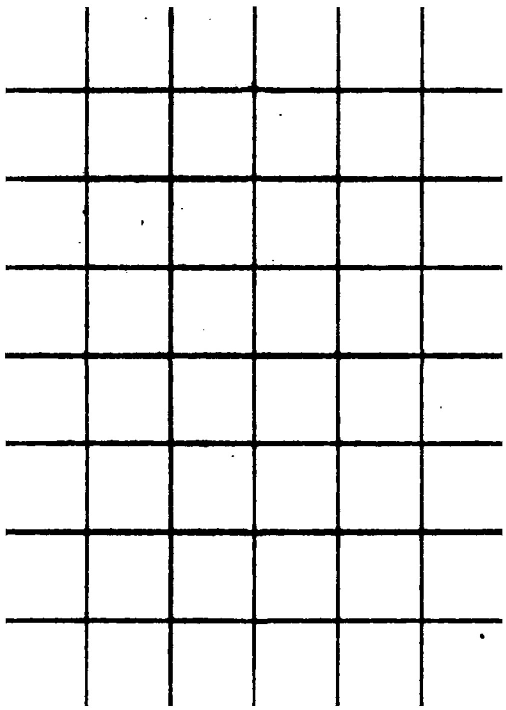
WASH the film in clear running water for 5 to 10 minutes at 18.5 to 32°C (65 to 90°F), or for 3 to 5 minutes at 32 to 40.5°C (90 to 105°F).

Rapid Wash: To reduce washing time and conserve water, rinse the film in running water for 20 seconds; then immerse it in KODAK Hypo Clearing Agent for 1 minute, followed by a 1-minute final wash with at least one change of running water at the temperature of the other processing solutions.

DRY in a dust-free area.

FIGURE C-3. Film Characteristics (Cont'd)

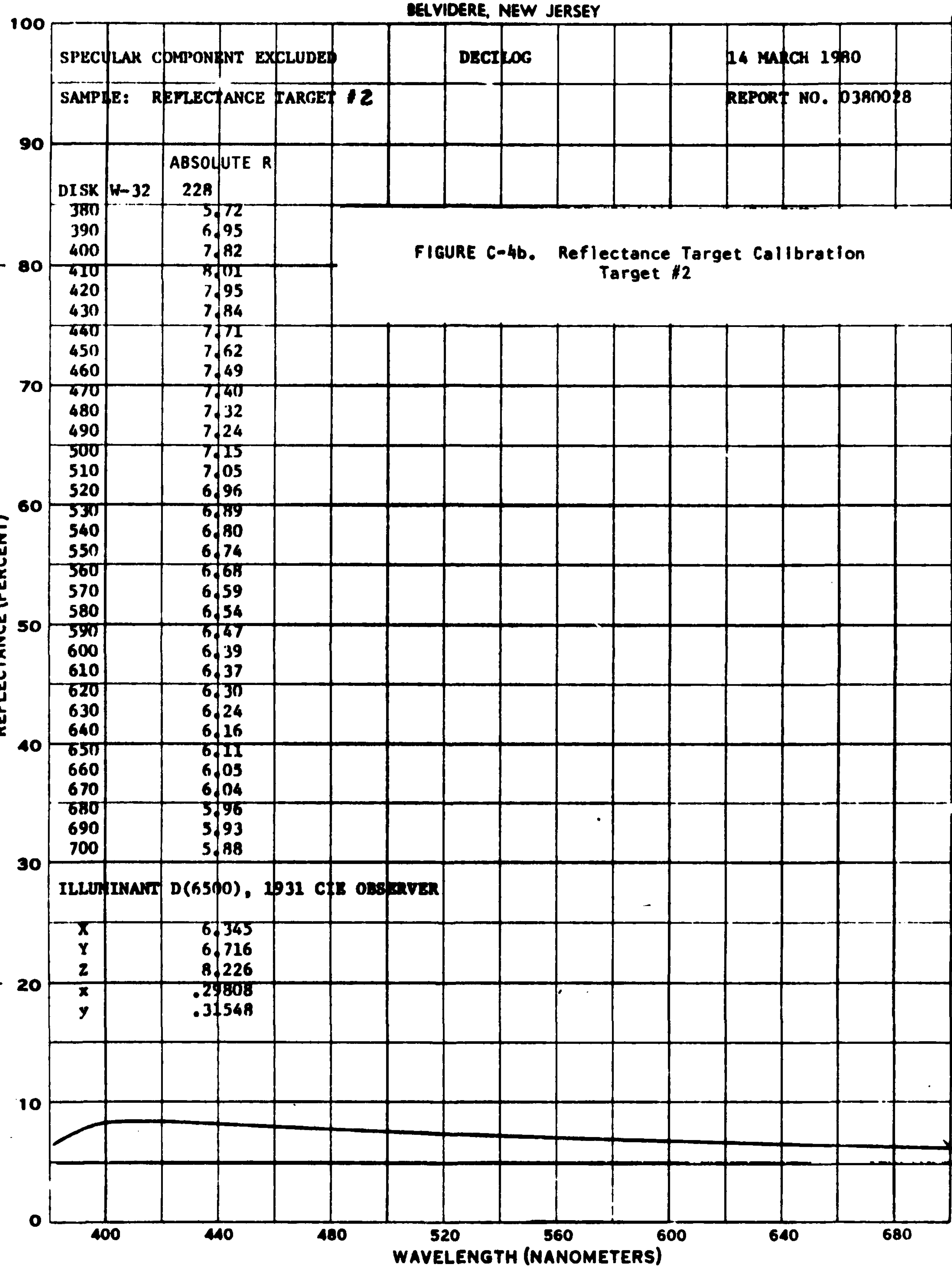
**FIGURE C.4 Reflectance Target Calibration
is the following 5 Pages**



HEMMENDINGER COLOR LABORATORY
BELVIDERE, NEW JERSEY

SPECULAR COMPONENT EXCLUDED   DECILOG   14 MARCH 1980

SAMPLE: REFLECTANCE TARGET #2   REPORT NO. 0380028



DISK W-32	ABSOLUTE R 228
380	5.72
390	6.95
400	7.82
410	8.01
420	7.95
430	7.84
440	7.71
450	7.62
460	7.49
470	7.40
480	7.32
490	7.24
500	7.15
510	7.05
520	6.96
530	6.89
540	6.80
550	6.74
560	6.68
570	6.59
580	6.54
590	6.47
600	6.39
610	6.37
620	6.30
630	6.24
640	6.16
650	6.11
660	6.05
670	6.04
680	5.96
690	5.93
700	5.88

ILLUMINANT D(6500), 1931 CIE OBSERVER

X	6.345
Y	6.716
Z	8.226
x	.29808
y	.31548

FIGURE C-4b. Reflectance Target Calibration Target #2

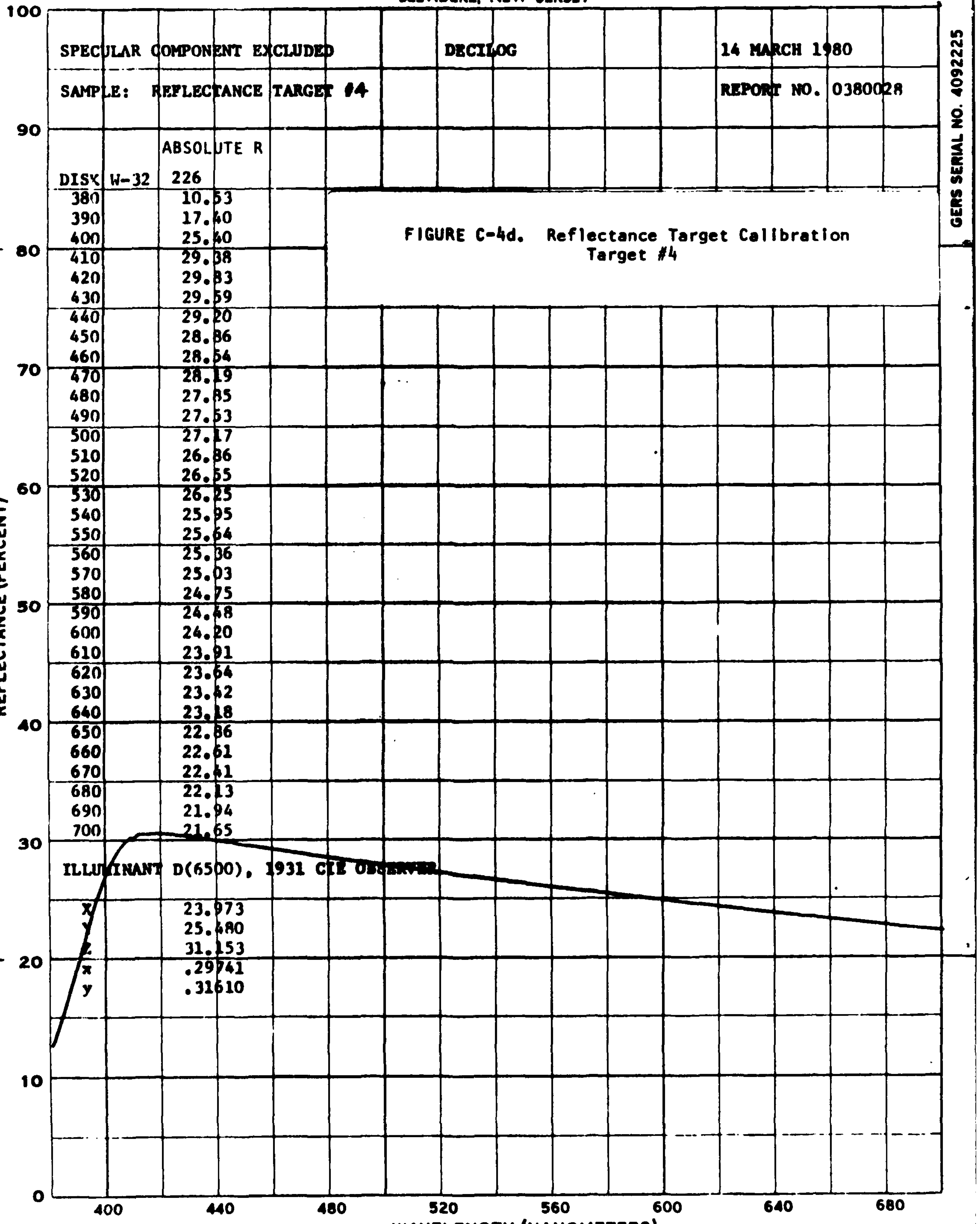
	15.69								
	15.45								
	15.23								
	15.01								
	14.78								
	14.59								
	14.35								
	14.18								
	13.97								
	13.75								
	13.57								
	13.37								
	13.23								
	13.04								
	12.87								
	12.70								
	12.56								
	12.38								
	12.23								
	12.05								
	11.92								

HEMMENDINGER COLOR LABORATORY
BELVIDERE, NEW JERSEY

SPECULAR COMPONENT EXCLUDED — DECILOG — 14 MARCH 1980

SAMPLE: REFLECTANCE TARGET #4 — REPORT NO. 0380028

GERS SERIAL NO. 4092225



DISK W-32	ABSOLUTE R 226
380	10.53
390	17.40
400	25.40
410	29.38
420	29.83
430	29.59
440	29.20
450	28.86
460	28.54
470	28.19
480	27.85
490	27.53
500	27.17
510	26.86
520	26.55
530	26.25
540	25.95
550	25.64
560	25.36
570	25.03
580	24.75
590	24.48
600	24.20
610	23.91
620	23.64
630	23.42
640	23.18
650	22.86
660	22.61
670	22.41
680	22.13
690	21.94
700	21.65

ILLUMINANT D(6500), 1931 CIE OBSERVER

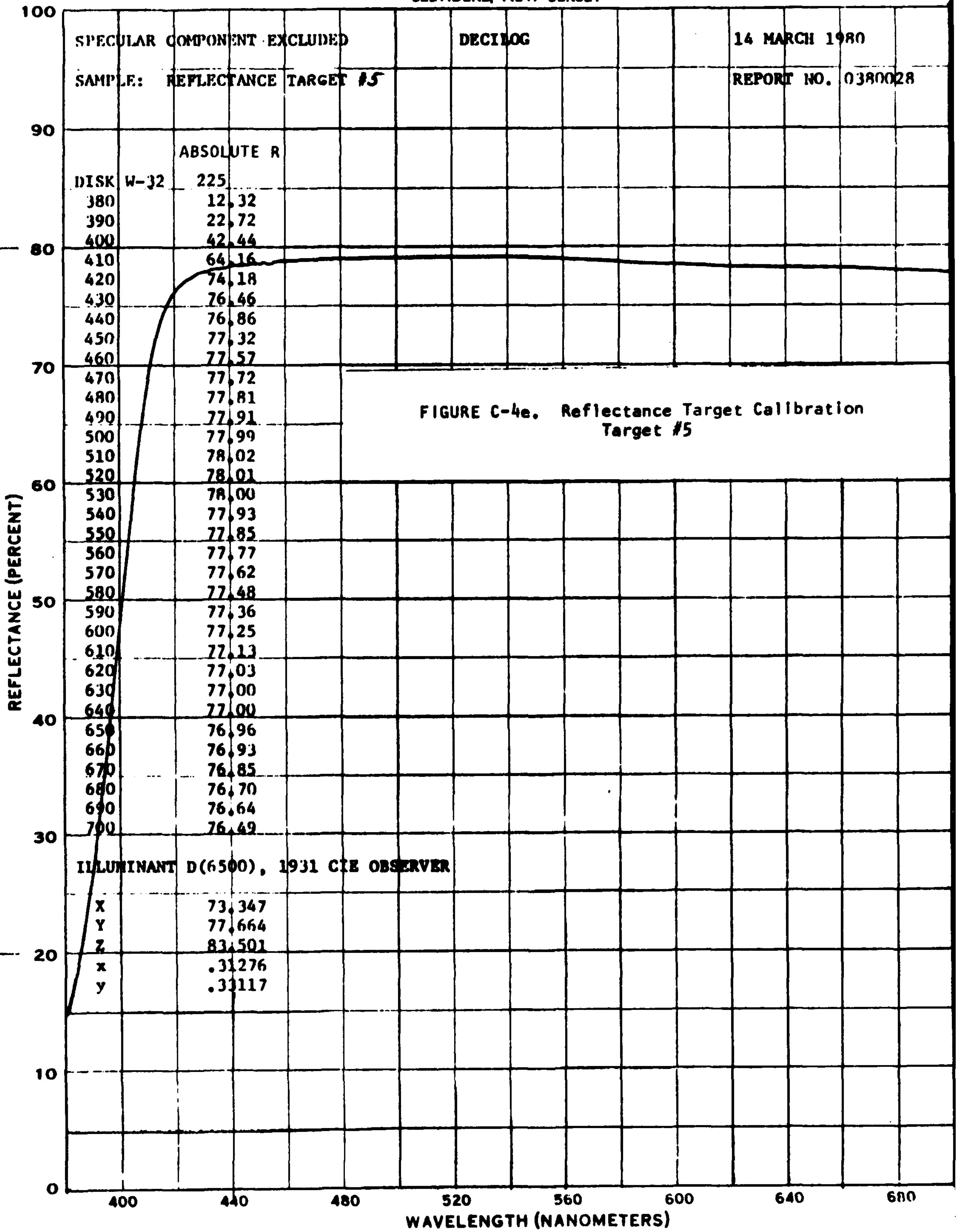
X	23.973
Y	25.480
Z	31.153
x	.29741
y	.31610

FIGURE C-4d. Reflectance Target Calibration Target #4

HEMMENDINGER COLOR LABORATORY
BELVIDERE, NEW JERSEY

SPECULAR COMPONENT EXCLUDED — DECILOG — 14 MARCH 1980

SAMPLE: REFLECTANCE TARGET #5 — REPORT NO. 0380028



ABSOLUTE R

DISK	W-32	225
380		12.32
390		22.72
400		42.44
410		64.16
420		74.18
430		76.46
440		76.86
450		77.32
460		77.57
470		77.72
480		77.81
490		77.91
500		77.99
510		78.02
520		78.01
530		78.00
540		77.93
550		77.85
560		77.77
570		77.62
580		77.48
590		77.36
600		77.25
610		77.13
620		77.03
630		77.00
640		77.00
650		76.96
660		76.93
670		76.85
680		76.70
690		76.64
700		76.49

ILLUMINANT D(6500), 1931 CIE OBSERVER

X	73.347
Y	77.664
Z	83.501
x	.31276
y	.33117

FIGURE C-4e. Reflectance Target Calibration Target #5